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Marine Ecological Risk Assessment at Naval Construction Battalion Center, Davisville, Rhode Island

&EPA

Phase I

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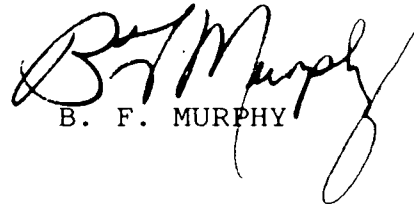
From: Commanding Officer, Naval Construction Battalion
        Center, Davisville, RI 02854-1161

SUBJ: FINAL REPORT: RISK ASSESSMENT PILOT STUDY, PHASE I

Here are the results of research and monitoring done to
evaluate adverse effects from hazardous waste disposal
activities at the Naval Construction Battalion Center (NCBC)
Davisville on Allen Harbor and nearby Narragansett Bay. The
Naval Ocean Systems Center (NOSC) and the EPA Environmental
Research Laboratory Narragansett (ERLN) cooperated to
produce this study.

This report describes the objectives and the data from the
first year of this multi-year study. It gives a preliminary
ecological risk assessment for Allen Harbor and Narragansett
Bay, supporting the Comprehensive Environmental Response
Compensation and Liability Act Remedial Investigation and
Feasibility Study for NCBC. All data and information herein
were presented at Technical Review Committee meetings at
NCBC and are approved for public release.

If you have any questions or comments on the report please
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B. F. MURPHY

ORIGINAL HOME OF THE SEABEES

PREFACE

In 1988, the Environmental Protection Agency's (EPA) Environmental Research Laboratory at Narragansett (ERLN), Rhode Island, and the Naval Ocean Systems Center (NOSC), entered into a Memorandum of Agreement (MOA) to develop cooperative research and monitoring activities for conducting ecological risk assessments. Under this agreement, case studies were developed to characterize the risk of Navy hazardous waste disposal sites that could affect aquatic ecosystems. This joint research supports the Navy's response to the requirements of the Comprehensive Environmental Response Compensation and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendment and Reauthorization Act of 1986 (SARA). Additionally, case studies under the agreement enabled ERLN and NOSC to develop and refine methods for examining ecological risks associated with anthropogenic wastes in the marine environment.

The first case study developed under the MOA was the Risk Assessment Pilot Study (RAPS), conducted at the Naval Construction Battalion Center (NCBC) Davisville, Rhode Island. NCBC Davisville is on Narragansett Bay, directly adjacent to a small embayment known as Allen Harbor. In 1984, the Rhode Island Department of Environmental Management closed Allen Harbor to shellfishing due to possible contamination from disposal sites located at NCBC Davisville. Two sites at NCBC Davisville were of particular concern: a 15-acre landfill next to Allen Harbor and Calf Pasture Point, which separates Allen Harbor from the West Passage of Narragansett Bay. The landfill had been used from 1946 to 1972 for the disposal of a variety of wastes, including solvents, polychlorinated biphenyl (PCB) contaminated oils, preservatives, sewage sludge, chromic acid, and construction rubble (Naval Energy and Environmental Support Activity [NEESA], 1984). Calf Pasture Point was used from 1960 to 1974 for disposal of calcium hypochlorite, chloride, and decontaminating solutions in a cement-lined pit (NEESA, 1984). The transportation of contaminants from these two sites posed a potential risk to the ecological systems of Allen Harbor and Narragansett Bay.

The RAPS for Allen Harbor was designed to provide specific quantitative information on the effects of the hazardous waste disposal sites on the water and sediment quality of Allen Harbor and Narragansett Bay. This study will be integrated with data obtained from a concurrent investigation to characterize disposal site conditions to develop the most effective remedy and risk management plans for the disposal sites at NCBC Davisville. Together these studies are intended to provide information necessary to complete the Remedial Investigation/Feasibility Study (RI/FS) process required by CERCLA and SARA.

This report presents the results of the first phase of the RAPS developed under the MOA between NOSC and ERLN. The data and analyses described here address the question of whether there is significant environmental stress in Allen Harbor, and provide information on how the disposal sites may affect the aquatic ecosystem. This effort has involved the participation of several research teams, facilities, and agencies, including the U.S. Food and Drug Administration, the U.S. Public Health Service Northeast Technical Services Unit, the University of Rhode Island, the Narragansett Bay Project, Science Applications International Corporation (SAIC), and TRC Environmental Consultants, Inc. At this writing, assessment activities are continuing in Allen Harbor to confirm the results obtained during Phase I. These efforts are aimed at characterizing and identifying pollution sources and developing a long-term monitoring plan to continuously verify environmental health in Allen Harbor. Results of these efforts will be provided as they become available.

WRM
RKJ
31 May 1990

ACKNOWLEDGMENTS

EXECUTIVE SUMMARY

OBJECTIVE

To undertake a marine ecological risk assessment at the Naval Construction Battalion Center (NCBC), Davisville, Rhode Island, to determine the effect of hazardous waster disposal on Allen Harbor and Narragansett Bay. Allen Harbor, located in Narragansett Bay at NCBC Davisville, was closed to shellfishing by the Rhode Island Department of Environmental Management because of suspected hazardous waste contamination from a landfill and disposal area adjacent to the harbor. A 15-acre landfill received a wide variety of wastes, including sewage sludge, solvents, paints, chromic acid, PCB-contaminated waste oils, preservatives, blasting grit, and other municipal and industrial wastes generated at NCBC Davisville and at the Naval Air Station (NAS) Quonset Point between 1946 to 1972. Another site, also adjacent to Allen Harbor on Calf Pasture Point, was used for the disposal of calcium hypochlorite decontaminating solution and chlorides.

APPROACH

A phased approach was developed to assess the ecological risks to Allen Harbor and Narragansett Bay posed by these hazardous waste sites. This report covers Phase I, the collection of environmental data that characterize the natural resources, sediment and water quality, and toxicology of indigenous and feral marine organisms of Allen Harbor and nearby Narragansett Bay. These data were evaluated to determine if there were adverse ecological effects from the disposal sites.

RESULTS

This Phase I study showed no major environmental problems unique to Allen Harbor, but do call into question some aspects of water and sediment quality. Most notably, mussels deployed in the harbor consistently showed reduced physiological condition compared to those exposed at other stations in Narragansett Bay. Effects were observed on the early life-stage processes of sea urchins and in biomarker assays; an increased incidence of hematopoietic neoplasia in the soft-shell clam *Mya arenaria* was also associated with proximity to Allen Harbor. A general lack of effects on higher levels of biological organization confounds the picture; little toxological impact on amphipods, relatively healthy *in situ* populations of benthic organisms, and relatively low levels of contaminants in sediments and tissues were measured in Allen Harbor relative to the other stations in Narragansett Bay. The contribution of the landfill to current environmental problems within the harbor, as well as that of boating activity and runoff from the surrounding landmass, are being examined more closely in Phase II.

CONTENTS

FIGURES

TABLES

ABBREVIATIONS AND ACRONYMS

A	—	Aroclor
AA	—	atomic absorption
ACH	—	atypical cell hyperplasia
AET	—	Apparent Effects Threshold
amu	—	atomic mass unit
ANCOVA	—	analysis of covariance
ANOVA	—	analysis of variance
ARAR	—	applicable or relevant and appropriate requirement of environmental quality
B(a)P	—	benzo(a)pyrene
BC	—	toxicological benchmark concentration
BrdUrd	—	5-bromodeoxyuridine
BRH	—	Black Rock Harbor
CC	—	Coggeshall Cove
CERCLA	—	Comprehensive Environmental Response Compensation and Liability Act of 1980
CHOLN	—	cholestanol
CHOLR	—	cholesterol
CLAS	—	Chromatography Laboratory Automation System
CLIS	—	Central Long Island Sound
COPROS	—	coprostanol
DDD	—	dichlorodiphenyldichloroethane
DDE	—	dichlorodiphenyldichloroethene
DDT	—	dichlorodiphenyltrichloroethene
DFTPP	—	decaflurotriphenylphosphine
DoD	—	Department of Defense
DI	—	deionized water
DMSO	—	dimethylsulfoxide
ECD	—	electron capture detection
EEC	—	expected environmental concentration
EICP	—	extracted ion current profile
ERLN	—	Environmental Research Laboratory, Narragansett
ER-L	—	Effects Range-Low
FDA-NETSU	—	Food and Drug Administration and Public Health Service Northeast Technical Services Unit

FID	—	flame ionization detection
FPD	—	flame photometric detector
GB	—	Greenwich Bay
GC	—	gas chromatograph
GJIC	—	gap-junctional intercellular communication
HCB	—	hexachlorobenzene
HGA	—	heated graphite atomization
HGPRTase	—	hypoxanthine-guanine phosphoibosyl transferase
HN	—	hematopoietic neoplasia
IAS	—	initial assessment study
ICP	—	inductively coupled plasma
i.d.	—	internal diameter
IRP	—	Installation Restoration Program
IS	—	internal standard
ISC	—	EPA Interim Sediment Criterion
LC50	—	concentration lethal to 50% of test subjects
LIMS	—	laboratory information management system
LOEL	—	lowest observed effect level
MAB	—	meters above bottom
MBS	—	meters below the surface
MC	—	metabolic cooperation
MHS	—	mercury/hydride system
MOA	—	Memorandum of Agreement
MP	—	Marsh Point
MS	—	mass spectrometer
MV	—	Mount View
na	—	not available
NBH	—	New Bedford Harbor
NCBC	—	Naval Construction Battalion Center
nd	—	not detected
NEESA	—	Naval Energy and Environmental Support Activity
NIST	—	National Institute of Standards and Technology
NJ	—	North Jamestown
nm	—	not measured
NOAA	—	National Oceanic and Atmospheric Administration
NOEL	—	no observable effect level

NOSC	—	Naval Oceans System Center
NPL	—	National Priorities List
NRCC	—	National Research Council of Canada
ns	—	not significant
OSI	—	Organism Sediment Index
PAH	—	polycyclic aromatic hydrocarbon
PC	—	Potter Cove
PCB	—	polychlorinated biphenyl
PHEN	—	phenanthrene
PID	—	photoionization detector
PI	—	Prudence Island
PSUM	—	sum of parent PAH compounds
QA	—	quality assurance
QL	—	quantitation list
RA	—	remedial action
RAPS	—	risk assessment pilot study
REMOTS	—	Remote Ecological Monitoring of the Seafloor System
RF	—	response factor
RRF	—	relative response factor
RI/FS	—	remedial investigation/feasibility study
RIDEM	—	Rhode Island Department of Environmental Management
RPD	—	redox potential depth
RQ	—	risk quotient
RSD	—	relative standard deviation (coefficient of variation)
QA/QC	—	quality assurance/quality control
SAIC	—	Science Applications International Corporation
SARA	—	Superfund Amendment and Reauthorization Act of 1986
SCE	—	sister chromatid exchange
SCT	—	sea urchin sperm cell test
SFG	—	Scope for Growth
SI	—	site investigation
SOP	—	standard operating procedure
SRM	—	standard reference material
TBT	—	tributyltin
TOTPCB	—	total polychlorinated biphenyls
TRC	—	Technical Review Committee

TRC-ECI	—	TRC Environmental Consultants, Inc.
URI-GSO	—	University of Rhode Island Graduate School of Oceanography
UV	—	ultraviolet
VOC	—	volatile organic compound
V79	—	V79-strain Chinese hamster cells
WQC	—	water quality criterion
6TG	—	6-thioguanine

INTRODUCTION

BACKGROUND

The Naval Construction Battalion Center (NCBC), Davisville, Rhode Island, is currently being investigated under the Department of Defense (DoD) Installation Restoration Program (IRP) and pursuant to Section 120 of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) to determine the occurrence and extent of environmental hazards resulting from routine operating procedures and past waste-disposal practices. Three steps are involved in this investigation. An initial assessment study (IAS) or site investigation (SI) is carried out to locate, collate, and evaluate any existing evidence of environmental contamination at the installation. Should the SI indicate potential environmental problems, a remedial investigation/ feasibility study (RI/FS) is conducted to verify or refute the existence of significant contamination, and to identify appropriate remedial actions should contamination exist. The third step of this process is to conduct remedial action (RA) to remedy environmental hazards of existing contamination, if necessary.

Fourteen sites at NCBC were identified to be potentially contaminated (NEESA, 1984). Thirteen of these, plus an additional seven requested by the State of Rhode Island, are currently included in the RI/FS being conducted by TRC Environmental Consultants, Inc. (TRC-ECI). General descriptions of these sites, as well as an overview of the RI/FS, are given in TRC-ECI (1986). NCBC Davisville was added to the National Priorities List (NPL), effective 15 November 1989.

Two of the sites recommended by the SI for further study are of particular interest for the marine environment. These sites—Site 7 (Calf Pasture Point) and Site 9 (the Allen Harbor Landfill)—are directly adjacent to Allen Harbor and Narragansett Bay (figure 1). From 1960 to 1974, Calf Pasture Point was used for the disposal of calcium hypochlorite, chloride, and decontaminating solution. From 1946 to 1972 the landfill was used for the disposal of a variety of wastes, including solvents, PCB-contaminated oils, preservatives, sewage sludge, chromic acid, and construction rubble. From the volume and nature of the waste material disposed of at these sites, as well as the known toxicity of many of the constituent contaminants, Allen Harbor and Narragansett Bay were thought to be at risk from environmental contamination. In 1984, Allen Harbor was closed to shellfishing by the Rhode Island Department of Environmental Management (RIDEM) because of possible contamination from the disposal sites at Narragansett Bay.

In 1988, an interagency Memorandum of Agreement (MOA) was entered into by the Naval Ocean Systems Center (NOSC), San Diego, California, and the U.S. Environmental Protection Agency's (EPA) Environmental Research Laboratory at
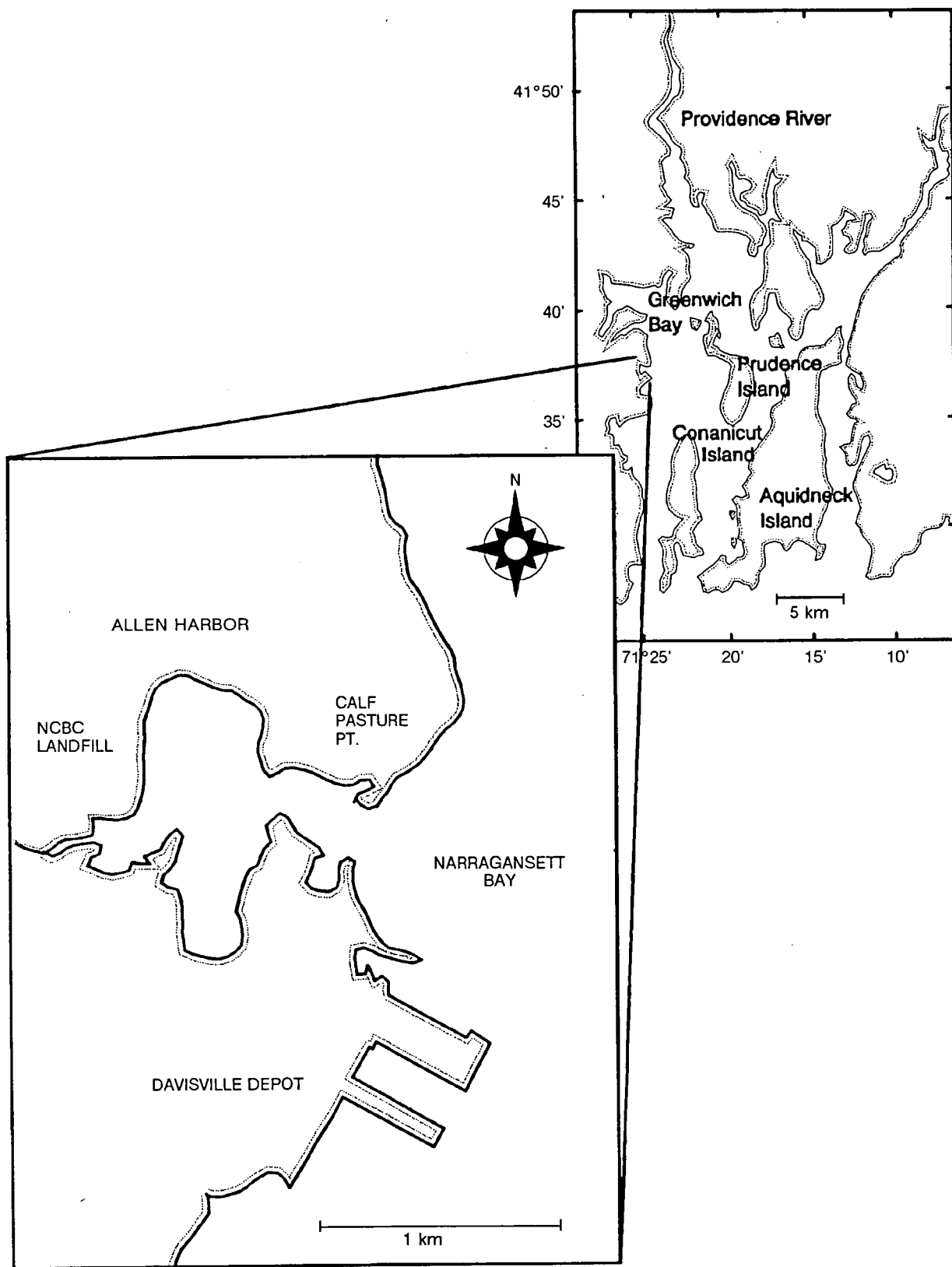
Figure 1. Allen Harbor and the locations of the landfill and Calf Pasture Point.

Narragansett (ERLN), Rhode Island, to jointly develop and implement procedures to assess ecological risks to marine systems associated with Navy installations. Allen Harbor was identified as the site for the first case study under this MOA and for the application of the new methodologies being developed and refined at ERLN.

The primary objective of this risk assessment pilot study (RAPS) is to determine the presence and extent of adverse ecological effects in Allen Harbor and Narragansett Bay as related to the RI/FS for NCBC Davisville. This information will be used to identify and select remedial alternatives and to design monitoring protocols to establish the continued effectiveness of selected remedial activities. A phased approach, somewhat analogous to that used in the IRP, was developed for this study:

Phase I—**Information Gathering**. To determine the existence, nature, and extent of adverse effects in Allen Harbor and Narragansett Bay resulting from contaminants originating from NCBC. The specific activities involved in this step include identifying and collating existing data and information relevant to the ecology of Allen Harbor, characterizing sediments and the water column in the harbor and nearby areas of Narragansett Bay, evaluating the natural resources of Allen Harbor relative to nearby areas of Narragansett Bay, and developing a preliminary ecological risk assessment of Allen Harbor.

Phase II—**Verification and Quantification of Toxicological Effects**. To verify the lack of adverse environmental effects (Option I), or to determine the nature and extent of contaminant effects on the marine system (Option II). If Option I is indicated, studies are to be conducted to confirm the lack of negative effects. Additionally, a monitoring strategy is to be developed to continuously verify environmentally safe levels. A final marine ecological risk assessment for NCBC Davisville would also be developed. If Option II is indicated, detailed characterizations of contaminant concentration and movement are to be developed. Further, studies are to be conducted of the toxicological mechanisms of implicated contaminants. Criteria are to be identified to evaluate remedial alternatives, and a monitoring plan that can evaluate remedial activities would be developed. An interim marine ecological risk assessment would be prepared.

Phase III—**Quantification of Ecological Risks**. To evaluate the effects of landfill exposure on marine organisms, establish exposure-response relationships, and develop an ecological risk assessment model. The primary activities of this phase will include performing laboratory exposure-response bioassays of water emanating from landfill seeps, from sediments associated with the landfill, and from extracts of sediments and soils associated with the landfill. The role of landfill contaminants in the induction of soft-shell clam

hematopoietic neoplasia will be evaluated and a long-term monitoring plan to continuously verify environmental safety will be developed.

The approach taken to address the objectives of Phase I, and the results of that approach is the subject of this report.

TECHNICAL APPROACH

The activities of Phase I were guided by the ecological risk assessment research strategy developed at ERLN (Bierman et al., 1986). This approach, as summarized in figure 2, requires information concerning (1) waste material (Waste Characterization); (2) physical and biological attributes of the site potentially affected (Ecosystem Characterization); (3) spatial and temporal distributions of the waste and associated contaminants (Exposure Assessment); and (4) responses of appropriate endpoints over the relevant range of exposure concentrations (Effects Assessment, also called Hazard Assessment). This information is synthesized into estimates of the risk associated with the release of waste material into the marine environment. Monitoring activities are subsequently instituted to provide relevant feedback to evaluate assessment procedures. This research strategy has been applied in case studies of the disposal of contaminated dredged material in Long Island Sound (Gentile et al., 1988a), and of sewage sludge disposal at the 106-Mile Deepwater Municipal Sludge Dump Site (Paul, 1987).
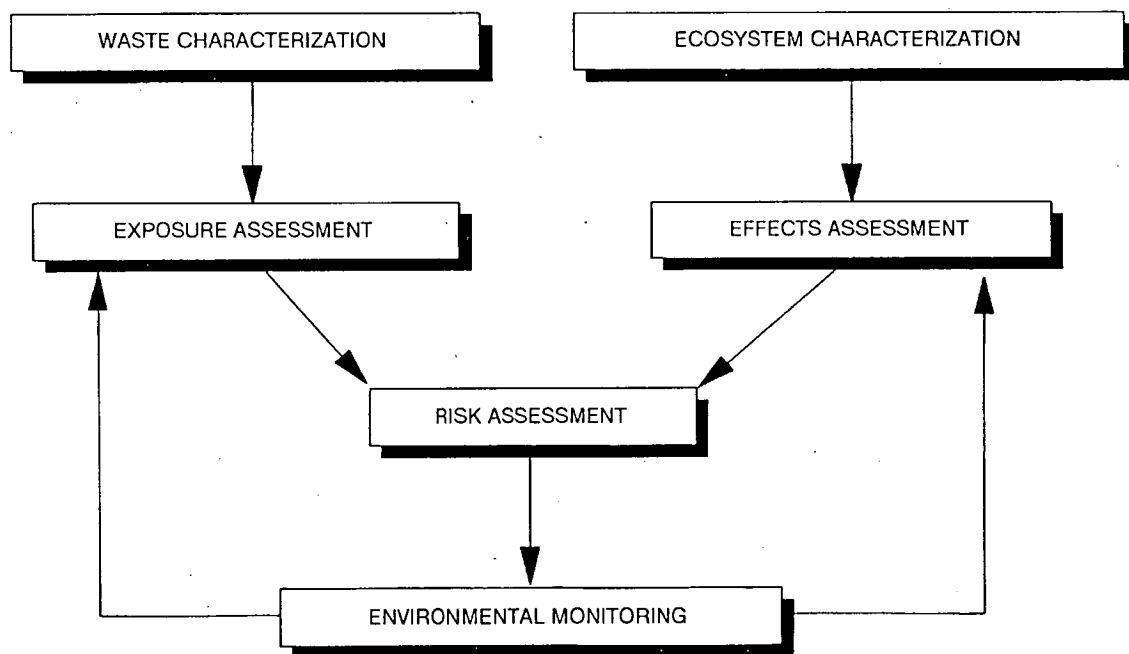
Figure 2. The ERLN ecological risk assessment paradigm.

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ERLN's risk assessment research strategy was originally developed to evaluate ocean disposal. A somewhat simpler approach is appropriate for studies involving in-place waste material, such as hazardous waste sites. In these cases, some modification to the ecosystem can reasonably be assumed to have taken place as the result of exposure to the waste material, so the activities associated with ecosystem characterization occur as part of the effects assessment. Additionally, the emphasis of both the exposure and effects assessments shifts from *a priori* analytical, numerical, and empirical model development to *a posteriori* quantification of effects that have (or have not) occurred. Thus, the majority of activity within these steps is field-oriented and empirical. How this modified risk assessment strategy is applied is described below.

Waste Site Characterization

The waste site characterization portion of the study centers primarily on identifying chemicals emanating from the disposal sites. Samples of water flowing from seeps on the face of the landfill, and of the sediments surrounding these seeps, were obtained for chemical analysis. With TRC-ECI, samples of groundwater from test wells and a single test pit were also obtained for analysis, as well as for quality assurance intercalibrations (see below). Additionally, the earlier SI provided descriptions of the variety of material disposed at the sites. This information was used to identify the variety and quantities of environmental contaminants which might be transported into the Harbor and nearby Narragansett Bay.

Exposure Assessment

From information obtained as part of the waste site characterization, the spatial distributions of specific contaminants were quantified through extensive field sampling efforts. Because fine-grained sediments typically act as reservoirs of anthropogenic contaminants, and therefore serve as integrators of contaminant flux through the system, samples of intertidal and subtidal sediments were obtained in Allen Harbor for detailed chemical and physical analysis. Additionally, several stations in the West Passage of Narragansett Bay were identified and sampled to address questions of contaminant movement and to provide reference comparisons. Although much more dynamic and often misleading with respect to contaminant concentration and movement, water column samples were also obtained within and outside the Harbor for chemical and bacteriological analysis. Tissue residues of contaminants in several resident biota were quantified to quantify the levels of exposure actually experienced by organisms. Native bivalves, including the quahog, *Mercenaria mercenaria*, the soft-shell clam, *Mya arenaria*, and the oyster, *Crassostrea virginica*, and an infaunal polychaete, *Nephtys incisa*, were obtained both within and outside of Allen Harbor for comparative purposes. These organisms exhibit a range of ecological lifestyles.

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Effects Assessment

The ecological effects of contaminants within Allen Harbor were evaluated through a combination of field sampling, field experimentation, and laboratory assays. These activities involved evaluating a number of biological endpoints shown to be sensitive to contaminant insult, and whose relationship with ecological well-being is fairly well established. Native *Mercenaria mercenaria*, *Mya arenaria*, and *Crassostrea virginica* were sampled for population abundance, individual condition, and histopathological effects. Collections again were obtained both within and outside of Allen Harbor for comparative purposes. The blue mussel, *Mytilus edulis*, was deployed at several stations to assess the effects of water quality on physiological condition and growth. Finally, the toxicity of sediments within Allen Harbor and at stations in Narragansett Bay was determined in the laboratory by using standard amphipod bioassays and biomarker tests under development at ERLN. These latter tests use field-exposed organisms or laboratory-exposed cell cultures to investigate the modes and mechanisms of contaminant effect on cellular and subcellular biological processes.

In this report, information obtained during these three steps is synthesized into a preliminary ecological risk assessment for Allen Harbor. Following completion of the subsequent two phases, the modified assessment will help in selecting remedial action (if needed) and an appropriate risk management plan for Allen Harbor. A long-term monitoring plan will be developed to evaluate the effectiveness of cleanup and site closure, and to verify the ongoing environmental health of Allen Harbor.

The risk assessment described here began in October 1988. The EPA-ERLN is the lead agency in this study, with the cooperation and participation of NOSC, the Food and Drug Administration and the Public Health Service Northeast Technical Services Unit (FDA-NETSU), the University of Rhode Island Graduate School of Oceanography (URI-GSO), and TRC-ECI. The remainder of this report describes the activities involved in each of the assessment steps outlined above. Appendix A is a copy of the MOA between NOSC and ERLN. Appendix B is a bibliography for Allen Harbor. FDA-NETSU activities and results are given in Appendix C, and a preliminary human health assessment for shell consumption is presented in Appendix D. Raw chemistry and biology data collected during Phase I activities are documented in Appendices E through N.

ASSESSMENT METHODS

The material in this section is organized to follow the steps of ERLN's risk assessment process. However, because quality assurance/quality control and analytical chemistry methods and procedures are common to all activities, their descriptions are given under separate headings. Certain activities were intended to provide information relevant to more than one assessment category (e.g., intertidal sediment chemistry provided information for both waste site characterization and exposure assessment). Methods associated with these are described only once, with cross-references provided as appropriate.

QUALITY ASSURANCE/QUALITY CONTROL

This project has been conducted in accordance with a quality assurance/quality control (QA/QC) plan (Gleason and Mueller, 1989). The QA/QC plan contains descriptions of ERLN standard operating procedures (SOPs), quality assurance steps for the specific activities of the project, and specific information on ERLN's Quality Assurance Facility Plan. A copy of this plan has been entered into the administrative record for NCBC Davisville and may be obtained by contacting ERLN or NCBC Davisville.

All data ger̄ āted during sample collection, preparation, and in some cases analysis were manuaḷiy entered into computerized databases for use in subsequent data reduction and statistical analysis. A description of the data management plan for this project is given in Rosen, Sheehan, and Petrocelli (1988). In addition to describing QA/QC for data storage, transfer, and manipulation, this document describes database design and its relationship to the interdisciplinary data management strategy at ERLN. This document is also part of the administrative record and may be obtained by contacting ERLN or NCBC Davisville.

A large number of the QA/QC procedures used for this study were specific to each type of activity. For example, the calibration of specific instrumentation is relevant only to the operation of that instrument. These procedures are best described during the discussion of each activity. Most of the QA/QC descriptions are therefore given where appropriate throughout the remainder of this Assessment Methods section.

In addition to the QA/QC activities internal to ERLN, an intercalibration exercise between ERLN and TRC-ECI was conducted to ensure the comparability of chemistry results. Sediments from the face of the landfill and water samples from landfill seeps, test wells, and a test pit were obtained in cooperation with TRC-ECI. These samples were split on site, and processed in accordance with SOPs. Strict chain-of-custody procedures were in effect during sample collection, transport, and analysis. The accompanying analyses were extensive for metals and organic compounds (see General Chemical Analysis Procedures below). FDA-NETSU and URI-GSO also participated in

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certain aspects of this exercise. Further, a standard reference material (SRM) was provided to ERLN by TRC-ECI. Analysis of this SRM not only provided an additional comparison of chemistry results, but also, through the comparison of results with the certified values, verified the accuracy of analytical procedures.

WASTE SITE CHARACTERIZATION

The characterization of wastes sites potentially affecting Allen Harbor involved chemical and bacteriological analyses of ground or perched water associated with the landfill, and of intertidal sediments associated with seeps located along the face of the landfill and at Calf Pasture Point. These samples were analyzed for organic, inorganic, and volatile organic contaminants, as delineated below. Information contained in the SI reports for NCBC Davisville provided additional insight into constituent hazardous materials in the waste sites.

Samples of landfill seep water were collected from four stations in August and September 1989. Organic samples were collected in Alconox-washed, solvent-rinsed, 1-liter amber bottles fitted with Teflon-lined caps. Inorganic samples were collected in acid-washed 250-ml polyethylene bottles. Samples were taken by immersing collection bottles into small, artificially created depressions below each seep. This procedure was necessitated by the extremely low flow rates associated with the seeps, and most likely caused some contamination of the water sample by entrained sediments. Artificially inflated contaminant concentrations may have resulted from the post-collection redistribution of contaminants between particulate and dissolved phases. Samples were placed on ice during transport to ERLN, and were stored at 4°C in a refrigerator until analyzed.

Ground and perched water was obtained during November 1989 from test wells installed in the landfill as part of ongoing RI/FS sampling activities conducted by TRC-ECI. Test wells were dug by auger to a depth of approximately 5 meters and allowed to stabilize for about 2 weeks before sampling. Sediment samples were also collected at various intervals by TRC-ECI during the drilling process. Well bores were approximately 10 cm in diameter. A manually lowered polyethylene sampling device was used to collect water samples, which were then poured into the appropriate sample containers (1-liter amber glass bottles with Teflon-lined caps for organics, 250-ml polyethylene bottles for inorganics, and clear 40-ml glass vials with Teflon-lined septa and one-hole caps for volatile organics). This sampling technique permitted some sediment to be incorporated into the water samples.

In addition to water from the test wells, water from a single test pit was sampled in September 1989 for both volatile organic compounds (VOCs) and inorganic contaminants. Test pits were constructed by using a backhoe under supervision of TRC-ECI. The pit was excavated until groundwater was encountered (approximately 5 meters

below the surface). Water was collected at that depth and returned to the surface, where it was poured into the appropriate sample containers. A rainstorm at the time of collection may have washed surface contamination into the test pit.

Special techniques were used during the collection and transport of VOC samples. Water samples were collected in clear 40-ml bottles, with Teflon-lined septa cap-liners fitted into one-holed caps. These were supplied precleaned from URI-GSO, where the subsequent analyses were conducted. Sample bottles were filled to overflowing and care was taken to ensure that no turbulence or air bubbles were added to the sample. The cap was replaced after each bottle was filled (with the Teflon-coated side facing the sample) in such a manner that no air bubbles were trapped in the bottle. Samples were collected in duplicate, stored on ice in the dark, and transferred to URI-GSO. Strict chain of custody records were maintained during all sample transfers.

EXPOSURE ASSESSMENT

The degree of exposure of resident biota to landfill and Calf Pasture Point contaminants was examined through a qualitative and quantitative description of chemical and biological contaminants in sediments and seawater. Tissue concentrations of contaminants were also used as a marker of exposure. These latter data were additionally used as a measure of biological effect (see below).

Twenty-nine permanent stations, 23 subtidal and 6 intertidal, were established in Allen Harbor (figure 3) and at several locations in Narragansett Bay (figure 4). The Allen Harbor stations included 11 subtidal stations (denoted AH1-AH11), and 3 intertidal stations (AH12–AH14). A fourth intertidal station was situated on the south shore of Calf Pasture Point (FDA). Information from these stations was used to characterize both exposure and effects within the harbor.

Seven additional subtidal stations (TTN1–TTN7) were situated along a T-shaped transect originating at the harbor mouth. These stations could be used to detect the transport of contaminants from Allen Harbor to Narragansett Bay proper. Four of the remaining 5 subtidal stations were situated mid-bay at the mouth of Greenwich Bay (GB), immediately north of Conanicut Island at an historically visited site called North Jamestown (NJ), directly off Mount View (MV) in the middle of the West Passage of the bay, and on the east side of Prudence Island in Potter Cove (PC). The fifth and sixth intertidal stations were situated mid-bay at Marsh Point (MP) and on the west side of Prudence Island in Coggeshall Cove (CC) (more appropriately Sheep Pen Cove). The position of these stations at mid-bay minimized any chance that comparisons between them would be distorted by the effects of north-to-south gradients in hydrographic parameters and water quality. Even though Allen Harbor is also situated mid-bay, the comparison of data from these other mid-bay stations with data obtained from Allen Harbor yielded information concerning the status of the harbor relative to
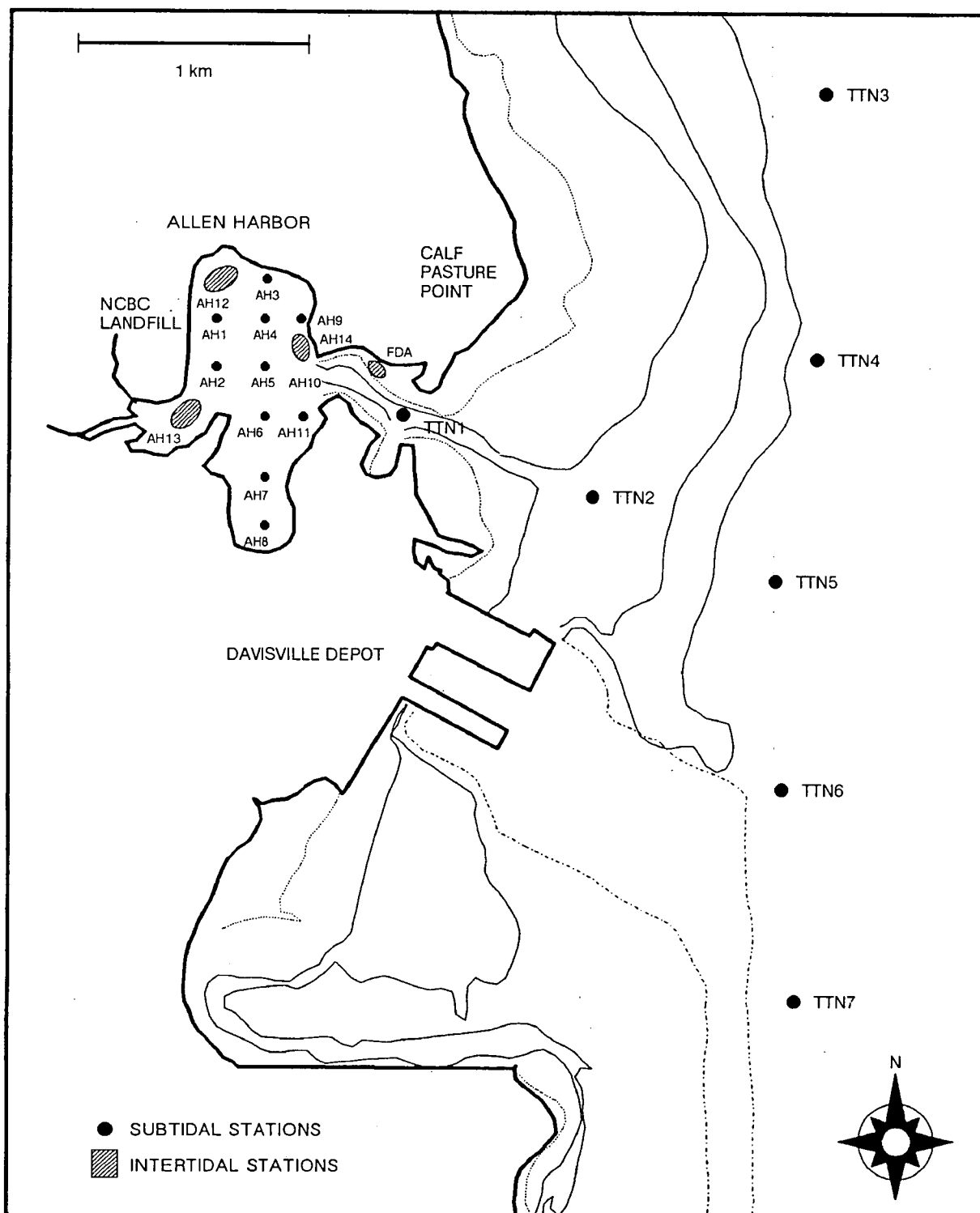
Figure 3. Sampling stations in Allen Harbor.
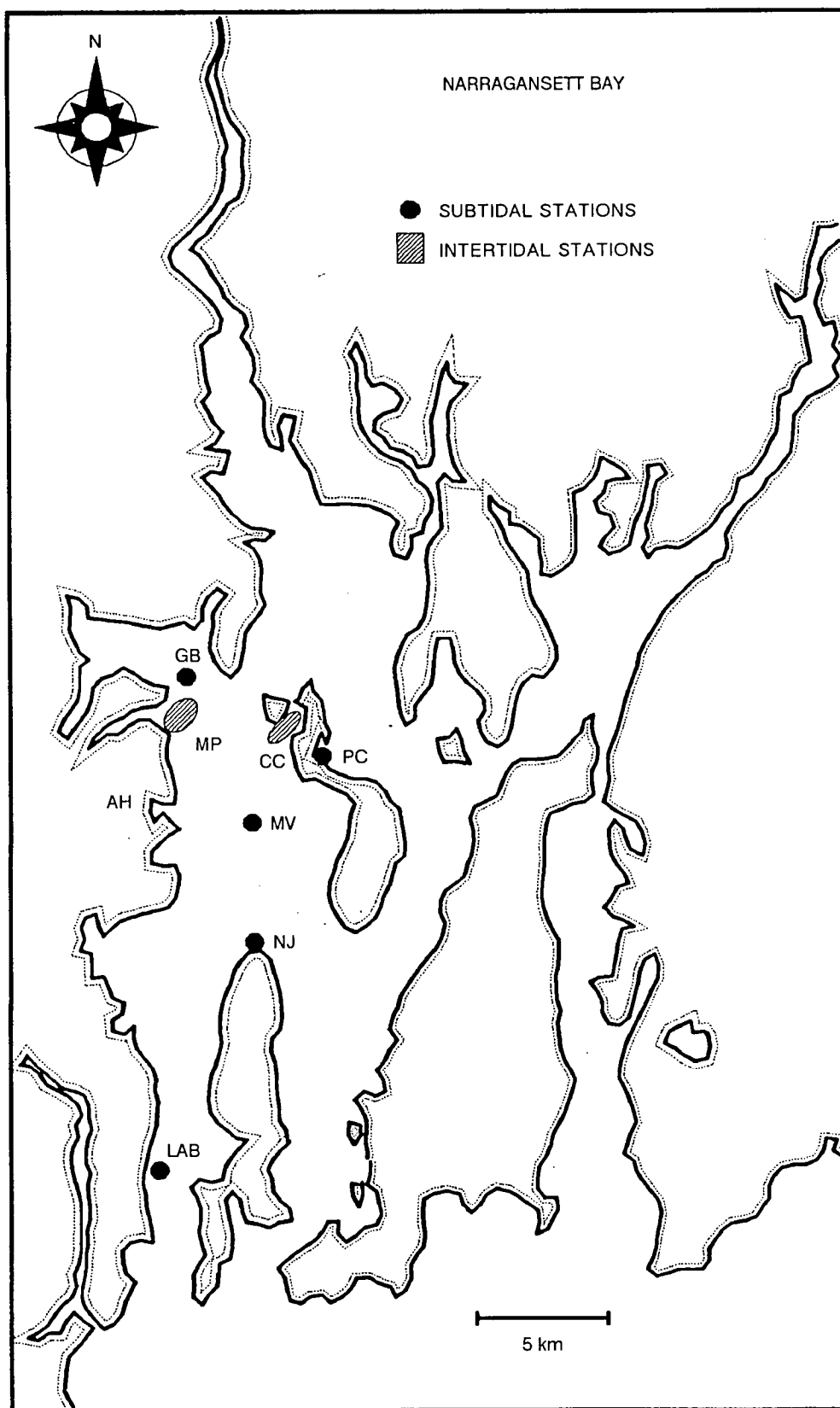
Figure 4. Sampling stations in Narragansett Bay.

the rest of Narragansett Bay. A final subtidal station (LAB) was located off the ERLN dock in the southern part of the bay to serve as a lower-bay reference.

Sediment Exposure

Subtidal and intertidal sediments were collected at all stations inside Allen Harbor and in Narragansett Bay proper. Samples were analyzed physically for particle size characteristics and chemically for a number of metals and nonpolar organic compounds. These contaminants included many identified in past studies as problem compounds in marine environments, and those identified in waste characterization exercises as potentially affecting Allen Harbor. A full accounting of quantified contaminants is given under general chemical analysis procedures below.

Collection Methods. Subtidal sediments were collected with a stainless steel Smith-McIntyre grab sampler. The top 2 cm of sediment from each grab was sub-sampled with a clean Teflon-coated scoop and placed in a glass jar. Deionized water was used to rinse the scoop between stations. The actual sampling design used for subtidal sediments involved compositing sediments from five replicate benthic grabs into single samples for each station in Allen Harbor. Five separate composites were similarly obtained from each of the mid-bay stations. The total composited sample size was approximately 1 gallon. Samples were stored on ice in an insulated cooler during transport to the laboratory and in walk-in refrigerators at 4°C before analysis. This material was also used for sediment effects testing, as will be described later.

Analyses were restricted to five stations (AH2, AH3, AH5, AH8, and AH10; see figure 3) for the quantification of exposure and effects associated with subtidal sediments in Allen Harbor. These stations were selected for their uniform coverage of the harbor. The remaining samples were archived for later analysis (if warranted). These five stations were treated as replicates of sediment conditions within Allen Harbor, and were compared with the five replicate composites collected at each of the mid-bay stations. Thus, statistical integrity was maintained in initial among-station comparisons at the same time that within-harbor conditions were evaluated.

Intertidal sediments were collected at all three Allen Harbor stations and at FDA, MP, and CC by manually removing the top 2 cm of sediment from the sediment surface with a prerinsed Teflon-coated scoop. This material was placed into precleaned 2-gallon glass jars. Sufficient sediments were collected from each location to half fill the jar. Samples were stored on ice in an insulated cooler, transported to the laboratory, and stored in walk-in refrigerators at 4°C before analysis. This material was also used for sediment effects testing, as will be described later.

Sediment cores were also obtained in February 1989 for chemical analysis at the five selected Allen Harbor stations. These were collected with a gravity corer and

acid-cleaned acrylic plastic core liners approximately 0.5 meter long and 7.5 cm in diameter. This arrangement sampled to a depth of at least 30 cm, the estimated depth of disturbance caused by previous shellfishing activity. A plastic end cap was placed on the top and bottom of each liner upon its retrieval. The cores were stored vertically on ice in coolers until their return to the laboratory. The samples were then composited by depth (top, middle, and bottom), homogenized, and stored in glass jars at 4°C before analysis.

Sediment Granulometry. The gross distribution of sediment grain size was determined at all subtidal and intertidal stations by using a sieve and centrifuge method. Following collection as described above, approximately 12 grams of each sample was dried at 80°C for 24 hour and weighed. A hydrogen peroxide solution (1:4 in water by volume) was added to the dried material. This suspension was allowed to stand for 24 hours. The sample was then sonicated for 10 seconds and washed through a 63-μm sieve with distilled H_2O. Material that collected on this sieve was dried and weighed to quantify the sand fraction (>63 μm). Material passing through the sieve was centrifuged at 1400 rpm for 83 seconds, followed by braking for 20 seconds. The supernatant (containing clay particles) was poured off, distilled water was reintroduced into the centrifuge tube, and the silt plus clay fraction remaining in the tube was resuspended by vigorous shaking. The centrifuging process was repeated several times until all clay particles were removed. The silt fraction remaining in the centrifuge tube was transferred to a beaker, dried for 24 hours at 80°C, and weighed. The proportion of clay in the original sample was determined by subtracting the weight of the sand and silt fractions from that of the total sample.

Water Column Exposure

Although past studies (e.g., Munns et al., 1988) have shown water column exposure conditions to be highly variable and extremely transient in tidally driven marine systems, attempts were made to quantify contaminant levels in the water column of Allen Harbor. Water samples were also collected at MV for purposes of comparison.

Large volume water samples were collected for organic chemistry analysis by using a shipboard pumping system equipped with a Teflon impeller (figure 5). Both dissolved and particulate-bound phase concentrations were quantified. A Teflon-lined stainless steel braided hose was lowered to the desired depths (0.5 meter above bottom (MAB) and 0.5 meter below the surface (MBS)) and seawater was pumped through a glass fiber filter (0.3 μm, 29.3-cm diameter, muffled at 450°C for 6 hours) to isolate particulate-bound contaminants. The filtered water was then passed through a series of foam plugs (Identi-plug, size C, precleaned with rinses of acetone and hexane) to isolate dissolved contaminants. The filter and foam plugs were held by a Millipore stainless steel holder and a Teflon housing, respectively. A water meter, located
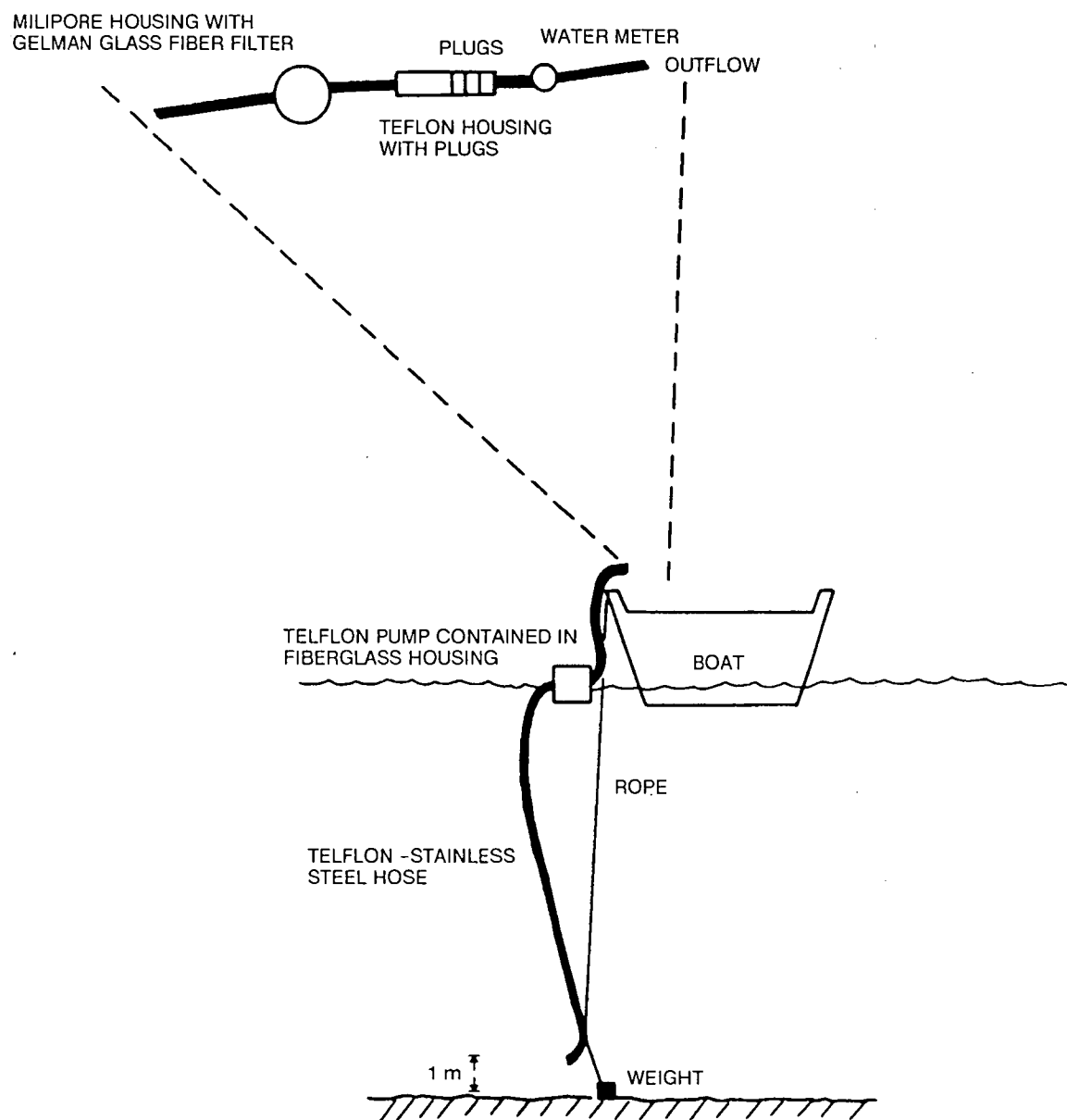
Figure 5. Schematic of large volume water sampling approach.

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downstream of the filter and plugs, measured the total volume of water delivered through the system. Approximately 30 liters of water was pumped to obtain a sample. Before to sample collection, the hose was rinsed by allowing several minutes of free pumping on station.

Following the collection process, filters were placed in a precleaned stainless steel bottle with metal forceps. The foam plug housing was removed and capped with aluminum foil. Filters and plugs were stored on ice during transport to the laboratory, and were stored frozen at –20°C before analysis.

Organism Collection for Residue Analysis

Several species of marine organisms were examined during Phase I activities to obtain information relevant to exposure conditions in Allen Harbor. In addition to blue mussel (*Mytilus edulis*) deployments, which are described below, indigenous oysters (*Crassostrea virginica*), quahogs (*Mercenaria mercenaria*), soft-shell clams (*Mya arenaria*), and polychaetes (*Nephtys incisa*) were collected at stations within and outside the harbor. These organisms were selected for their ecological and economic importance and for their well-studied responses to environmental contamination. In addition to yielding insight to sediment and water column exposure conditions, these species were also used to determine the effects of exposure conditions in the harbor. These organisms and their use in this study is described further in the effects assessment section below.

Quahogs. Professional quahog fisherman used bull rakes to collect *Mercenaria* at subtidal stations on a quarterly basis beginning in the fall of 1989. Twenty-five individuals were collected at each station, which were combined for chemical analysis as 5 composites of 5 animals each. Quahogs were stored on ice during transport to the laboratory and were frozen and stored at –20°C before chemical analysis.

Soft-Shell Clams. *Mya arenaria* were collected for tissue residue analysis from the three intertidal stations in Allen Harbor (AH12, AH13, AH14), FDA, MP, and CC. Clams were obtained in random fashion with clam rakes and garden forks, and were divided into 3 composites of 5 animals each for subsequent chemical analysis. Animals were stored on ice during transport to ERLN, and were stored frozen at –20°C before analysis.

Oysters. *Crassostrea* samples were collected at the beginning of the study only. Oysters were obtained from four locations by manually prying them from rocks and hard surfaces. Three of the collection sites were located along the face of the landfill. A professional oyster fisherman was commissioned to collect oysters from a control site at Prudence Island. A minimum of 25 oysters were collected from each site. These were transported and stored in a fashion identical to that used for quahogs and soft-shell clams.

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Polychaetes. Subtidal sediments from Allen Harbor (AH2) and Mount View were obtained with a Smith-MacIntyre grab sampler and wet-sieved through 1-mm-mesh stainless steel screens to collect composite samples of indigenous *Nephtys incisa*. Individual worms were picked with plastic forceps. Replicate grabs were processed in this fashion until 10 grams of worm tissue had been collected for trace metal analysis. Worms were placed in precleaned glass jars with Teflon-lined caps and kept on ice during transport to the laboratory. Samples were held frozen before chemical analysis.

Caged Mussel Deployments. Nonindigenous *Mytilus edulis* were used as surrogate species to provide exposure and effects information under controlled exposure conditions. They were deployed within Allen Harbor and Narragansett Bay during the spring and fall of 1989. Mussels were obtained by scallop dredge from a clean reference site near Dutch Island in Narragansett Bay one to two days before deployment. Approximately 100 individuals 5 to 7 cm long were placed into polyethylene baskets and deployed for 28 days at 1 meter above the bottom in cages tethered to subsurface buoys (figure 6). Replicate deployments were made at each of four stations: AH5, MV, TTN2, and LAB. At the end of the deployment period, cages were retrieved and transported on ice to ERLN. Tissue samples for chemical analysis were stored frozen before analysis.
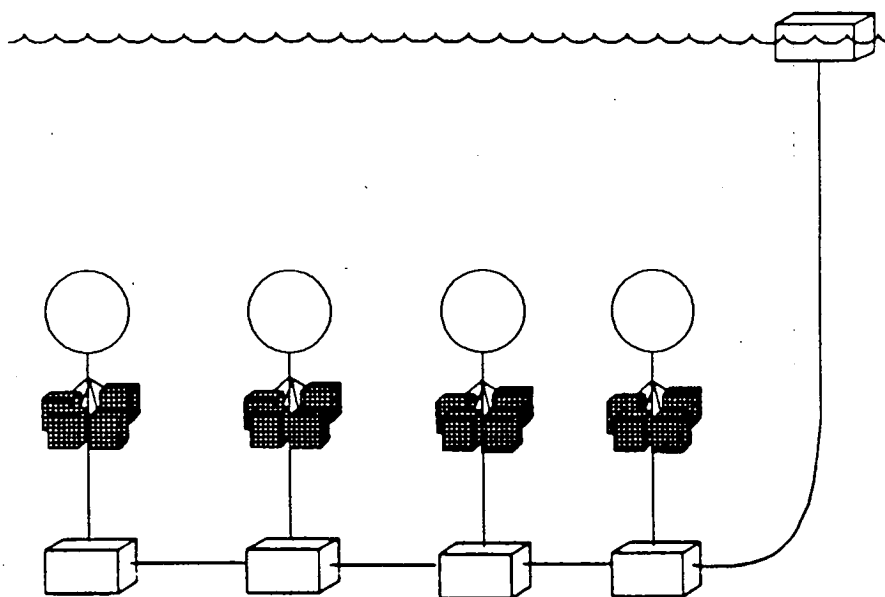
Figure 6. *Mytilus edulis* deployment arrangement.

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EFFECTS ASSESSMENT

The effects assessment portion of this study involved examining the biological effects of Allen Harbor sediment and water column quality on cytogenetic, physiological and histological condition, mortality, reproduction and development, population structure, and benthic community status. Additionally, contaminant bioaccumulation in shellfish and polychaete tissues was quantified as an indicator of potential adverse effects.

Assessment procedures were of three general types: (1) a description of the status of indigenous organisms collected *in situ*; (2) an experimental evaluation of biological endpoints in field-deployed organisms; and (3) a laboratory measurement of the toxicity of field-collected sediment and water samples. The following descriptions of the methods used in these assessments are organized around indigenous organism health, sediment effects, and water column effects.

Status of Indigenous Organisms

Shellfish were emphasized as indicators of the status of indigenous organisms in this study because of their ecological and commercial importance in Allen Harbor and Narragansett Bay. Furthermore, the harbor has been closed to commercial and recreational shellfishing by RIDEM since 1984 because of suspected contamination from the landfill. Thus, populations of the indigenous bivalves *Mercenaria mercenaria*, *Mya arenaria*, and *Crassostrea virginica* were assessed through field collection and laboratory measurement.

Quahogs are sedentary and filter large volumes of water during respiration and feeding activities, making them ideal for evaluating environmental quality. They are subtidal and infaunal, and support a large commercial fishery in Rhode Island. Soft-shell clams are also sedentary, but unlike quahogs, occur infaunally in intertidal areas. Although not particularly important to Rhode Island commercially, soft-shell clams support an active recreational fishery. Oysters are primarily subtidal, where they attach to the surfaces of hard substrate. Because of their relative scarcity, oyster harvests are limited primarily to recreational activity. All three species are appropriately classified as filter feeders.

Field collections of quahogs and soft-shell clams were obtained quarterly to estimate population density and structure, to quantify general condition based upon morphometric analysis, and to make histopathological observations. Oysters were collected at one time only. As described earlier, bivalves from the first quarterly sampling were also analyzed chemically.

Population Density and Structure. The first of the four quarterly samples of *Mercenaria* and *Mya* were collected quantitatively to provide information about population density and size structure. Collections made thereafter were qualitative and were designed to yield information about morphological condition only.

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Quahogs were collected by professional fishermen using bullrakes. Population size structure and condition index were determined by measuring shell length, whole weight, and tissue wet weight of 25 randomly selected individuals. Measurements were made immediately upon return of the animals to ERLN.

Quantitative samples of soft-shell clams were obtained during the first quarter by collecting all clams from three randomly placed 1-m2 quadrat frames. Each quadrat was excavated to a depth of approximately 35 cm by means of a clam rake or garden fork. All clams found within the quadrat were placed in a labelled bag and transported to the laboratory on ice. Twenty-five animals were sampled in random fashion at each station during the remaining quarterly collections. The condition index was determined in a manner similar to that described for quahogs.

Crassostrea was sampled once at two stations: Allen Harbor and the west side of Prudence Island. These collections were qualitative and provided information similar to that for the other bivalves (i.e., condition).

Histopathology. Indigenous bivalves from the quarterly collections and mussels from the first deployment were examined histologically to identify pathologies. The valves of quahogs, soft-shell calms, and deployed mussels were pried open, and the soft tissue (whole animal) was removed by passing a shellfish knife between the mantle and valves. Oysters were opened by inserting an oyster knife into the ligament and twisting to separate the valves. The knife was used to loosen and separate the mantle and adductor muscle from the dorsal valve, which was removed. The whole animal was removed from the ventral valve in similar fashion.

Whole animals of all species were fixed in Helly's solution for 15–30 minutes, sagittally sectioned along 95% of the midline, and returned to the fixative for 16–24 hours. Animals were sectioned transversely through the body mass, and then cut parasagittally into sections 2–3 mm thick. Tissues sections were washed overnight, embedded in paraffin, and microtomed to 6 μm. Thin sections were then stained with Harris hematoxylin and Eosin. Light microscopy was used to examine all major organ systems for pathology.

Sediment Effects

Composite sediment samples from Allen Harbor and the mid-bay stations were evaluated by using three types of toxicity tests: (1) acute toxicity to the amphipod *Ampelisca abdita*, (2) sea urchin fertilization and development, and (3) biomarker responses. These assays have been developed and refined at ERLN over the past several years, and have been successfully employed in a number of studies.

Sediments were collected as described previously and were tested in several forms: as whole sediment, as interstitial water, as whole sediment extract, or as fractionated

sediment extract. Interstitial water was prepared by placing 200 grams of sediment into a 250-ml Teflon tube and centrifuging at 4°C for 3 hours at 4000 rpm. The resulting supernatant was removed for testing. Method efficiency was measured by comparing chemical concentrations in the different extracts with the sediment water content (Hillel, 1982).

Whole sediment extracts were prepared by placing approximately 60 grams of homogenized sediment in a solvent-rinsed centrifuge tube. The sample was sonicated three times in acetonitrile with an ultrasonic probe. Each extract was centrifuged and poured off into a separatory funnel with pentane-extracted deionized water (DI). The DI/acetonitrile phase was back-extracted three times with pentane, and extracts were combined and dried over sodium sulfate. The sample was reduced twice in pentane, brought to dryness, and dissolved in dimethylsulfoxide (DMSO) for use.

Sediment extract fractions were prepared by charging 1 ml of whole extract onto a column of 7.5% deactivated silica gel (100–200 mesh Bio-Rad). Forty-five ml of pentane was added and collected as the PCB (f_1) fraction. This was followed by the addition of 36 ml of 30% (volume to volume) methylene chloride (CH_2Cl_2) in pentane to isolate the PAH and pesticide fraction (f_2). Thirty-six ml of CH_2Cl_2 was then added and collected as the f_3 fraction. This fraction contains moderately polar compounds such as sterols. Finally, 36 ml of methanol was passed through the column to collect extremely polar compounds as the f_4 fraction. Each fraction was volume-reduced in round bottom flasks and reconstituted in 1 ml of DMSO. The use of these fractions in bioassays helped determine the contaminant classes potentially responsible for any observed toxicity.

Amphipod Bioassay. The amphipod test was used to determine toxicity of composite whole sediment samples from 11 stations (three intertidal) in Allen Harbor, from NJ, GB, and MV, and from the intertidal stations MP and CC. Sediments from three locations on the face of the landfill were similarly tested.

Ampelisca abdita is a benthic particle feeder which obtains food from suspensions in the water column or directly from the sediment surface. It feeds from a membranous tube which extends some 3–4 cm into the sediment. In addition to being an important prey item for demersal fish such as flounder, *Ampelisca* can affect sediment entrainment and transport through the formation of dense beds of tubes. Above some critical tube density, these beds serve both to entrap suspended particulates and to armor the sediment surface from erosion. *Ampelisca* is relatively sensitive to a variety of contaminants associated with sediments (Gentile et al., 1988b; Breteler, Scott, and Shepherd, 1989).

Groups of subadult amphipods, collected from a reference area (Narrow River, Narragansett, RI) used in previous investigations, were exposed to homogenized batch sediments for 10 days with flowing seawater. Typically, 20 amphipods were used in

each of five replicate subsamples of each sediment. Assays were performed under standardized laboratory conditions, with control sediments (typically Central Long Island Sound (CLIS) reference sediment; see Breteler, Scott, and Shepherd, *ibid*) tested simultaneously to ensure appropriate test conditions. Exposure chambers were monitored daily, and dead animals were removed and recorded as found. At the end of the 10-day exposure, test sediments were sieved to remove living animals, which were preserved in 5% buffered formalin for sorting.

Mortality was analyzed as the endpoint of this assay. Mortality greater than 20% can be considered biologically important.* A complete description of this test can be found in Gleason and Mueller (1989).

Biomarker Assays. Sediment samples from Allen Harbor and Mount View were analyzed with two biomarker tests to further examine sediment quality. Biomarker tests are assays involving endpoints at the cellular or subcellular levels of biological organization. They are typically designed to provide rapid quantitative or qualitative information on the toxicity and modes of action of environmental stressors, such as anthropogenic contaminants. Ideally they can be used to predict biological response at ecologically more meaningful levels of organization (e.g., individual, population, community). They can also be used as markers of exposure to environmental stressors, that is, positive responses indicate environmental insult in the recent past.

The biomarker tests used in this study, although still considered under development, have been employed in a range of laboratory and field studies. Their development represents an ongoing program at ERLN. Because of their novelty, a fairly detailed rationale for their application is provided below.

Sister Chromatid Exchange. The Chinese hamster V79/sister chromatid exchange (V79/SCE) assay was used to investigate mutagenic activity associated with whole sediment extracts. Mutagenic and carcinogenic substances that may cause cytogenetic damage are often found in contaminated sediments. Increased cytogenetic damage is evidence of mutagenic events that can produce heritable, pathological effects (Heddle et al., 1983). The mutagenic activity of latent genotoxins in sediment samples can provide valuable information on the kinds of contaminants present in the environment.

The SCE response, as described by Taylor, Woods, and Hughes (1957), has become a useful method for measuring chemically induced DNA damage. An SCE represents the breakage and symmetrical exchange of DNA between the sister chromatids of a chromosome. SCE frequency often correlates with that of point mutation and is a more sensitive indicator of mutagenesis than is the more classical metaphase analysis of structural aberrations (Carrano et al., 1978; Latt, 1974). Dose-related SCE responses have been observed in both *in vivo* and *in vitro* studies, and the EPA's Gene-Tox

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*K. J. Scott, SAIC, personal communication.

Program has recommended SCE analysis for environmental applications (Latt et al., 1981).

The Chinese hamster V79 fibroblast cells were cultured in 100-mm plastic petri dishes at a density of 11×10^5 cells in 10 ml of modified growth medium, as described by Malcolm, Mills, and McKenna (1985). Cultures were incubated at 37°C in a 100% humidified atmosphere of 5% CO_2 in air for 24 hours to allow cell attachment. Exponentially growing cells were exposed for 5 hours to the sediment extracts, with and without S9 enzyme activation. Enzyme activation permitted the effects of contaminant metabolites on the cellular and cytogenetic responses to be examined. The S9 rat liver microsomal fraction, stored at –70°C and thawed immediately before use, was prepared by Organon Tecknika (Durham, NC) from Aroclor 1254-induced 8–10 week old Sprague–Dawley male rats obtained from Charles River Breeders and mixed with cofactors and serum-free medium for activation. The final concentrations of cofactors and S9 were 0.63 mg/ml NADP, 0.27 mg/ml G-6-P, and 15.6 μl/ml S9 fraction. The protein content in the S9 fraction, determined according to Lowry et al. (1951), was 38.4 mg/ml.

Following exposure, the cells were rinsed twice with Earle's Balanced Salt Solution and modified medium containing 3 μg/ml 5-bromodeoxyuridine (BrdUrd), and 5% fetal calf serum was added. Approximately 18 hours later, a 0.5 μg/ml solution of colcemid (a mitotic inhibitor) was added for 1 to 2 hours. Cells were collected by trypsinization, treated with potassium chloride (5.49 gm/L DI), and fixed twice in Carnoy's fixative (3 parts alcohol:1 part acetic acid). Cells were dropped on microscope slides, dried, and stained with Hoechst 33258 and Giemsa (Perry and Wolff, 1974). SCEs were scored visually with the aid of a light microscope.

Metabolic Cooperation. The Chinese hamster V79/metabolic cooperation (V79/MC) assay was used as a short-term biomarker test to identify tumor promoters in whole sediment extracts and sediment fractions. In the carcinogenic process, tumor promoters are theorized to exert their effects on already "initiated" or mutated cells by epigenetic mechanisms. Promotion is the mechanism that enables an initiated cell to expand clonally, a process which may eventually result in the formation of a recognizable tumor. In this assay, materials are tested for their ability to inhibit gap-junctional intercellular communication (GJIC) between co-cultured mutant and wild-type V79 Chinese hamster lung fibroblasts. Many established tumor-promoting chemicals or their metabolites inhibit GJIC and are detectable with this system.

The experimental procedures used here were adopted from Yotti, Chang, and Trosko (1979). The V79/MC assay uses co-cultivated mutant (HGPRT–) and wild-type (HGPRT+) Chinese hamster V79 lung fibroblasts. The mutants are deficient in the enzyme hypoxanthine-guanine phosphoribosyl transferase (HGPRTase). In addition to normal purine bases, HGPRTase catalyzes the biotransformation of certain abnormal

bases, such as 6-thioguanine (6TG), which are lethal when incorporated into DNA. Thus, 6TG is toxic to wild-type cells but not to HGPRTase-deficient cells, unless mutant and wild-type cells establish physical contact. If contact occurs, gap junctions between cells will allow the exchange of cytoplasmic components. Under such conditions, the toxic metabolite of 6TG (6-thioguanine monophosphate) is passed from wild-type to mutant cell, resulting in the death of both cell types. In the V79/MC assay, the phenomenon of mutant cell killing through MC in the presence of 6TG is used to identify and quantify the effects of test materials on MC.

Tests were conducted with an excess of wild-type cells to ensure physical contact between the two cell types. Under such conditions, mutant cells are killed upon exposure to 6TG unless "rescued" by test materials that inhibit MC. Thus, the ability of test materials to suppress MC is measured as an increase in mutant cell survival over background. It is also possible for materials to enhance MC. This situation is detected as a decrease in mutant cell survival below background.

In the laboratory, the effects of sediment extracts and fractions on MC were assessed only at concentrations permitting a relative cell survival of at least 70%. Thus, the effects of test chemicals were assessed essentially at noncytotoxic concentrations. Sediment extracts were prepared as described above. Responses were evaluated by applying the statistically conservative, two-fold increase rule (Ames, McCann, and Yamasaki, 1975). MC was considered significantly inhibited if experimental mutant survival exceeded solvent control mutant survival by a factor of two or more. MC was enhanced if the reverse was true.

Sea Urchin Fertilization, Development, and Survival. Sediment quality was further investigated by using sea urchin fertilization and larval development as endpoints. In the sperm cell toxicity test (SCT), sperm cell viability was determined by the percentage of successful fertilizations (Dinnel et al., 1983). Electrical stimulation was used to obtain gametes from laboratory-held adult *Arbacia punctulata*. Sperm and egg concentrations were diluted to 1×10^6 and 1,000 per ml, respectively. Sperm (100 μl) were added to 10 ml of a solution of the interstitial water in seawater (ranging in concentration from 0 to 100% interstitial water) at 20°C for 1 hour. A 1-ml suspension of unfertilized eggs was subsequently added. Formalin was added 20 minutes later and eggs were examined microscopically for the presence of a fertilization membrane (Nacci, Jackim, and Walsh, 1986). Responses were quantified as percent fertilized eggs.

In the sea urchin larval development assay, survival, development, and growth were measured to determine toxic effects on 48-hour pluteus larvae (Oshida, Goochey, Mearns, 1981). Spawning, fertilization, and exposure methods were completed as for the SCT. Formalin was added 48 hours after fertilization. Aliquots of pluteii were examined microscopically for survival and development, and 50 randomly selected individuals were evaluated by image analysis for area and length. Embryo survival was

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calculated as the difference between the number of fertilized eggs present in a 1-ml sample after 20 minutes and the number of pluteii present in a 1-ml sample after 48 hours.

Benthic Community Condition. The status of the benthic community within Allen Harbor was compared with that of several stations in Narragansett Bay by using the REMOTS™ benthic camera technology (Rhoads and Germano, 1982; Germano, 1983). REMOTS provides information on the physical, chemical, and biological characteristics of the seafloor by using the computer analysis of images of the vertical profile of the top 20 cm of sediment. *In situ* images were obtained by slowly lowering a platform-mounted prism into the sediment and photographing the undisturbed cross section of sediment revealed through the vertically oriented face of the prism. The benthic parameters quantified in this manner were used to formulate an index of habitat quality, the Organism-Sediment Index (OSI). This index ranges from -10 (no indication of macrofauna, shallow or no oxygen penetration into the sediment, sedimentary methane gas present) to +11 (healthy, mature macrofaunal community present, deep penetration of oxygen, no sediment methane); high habitat quality is indicated by high values of the OSI.

This work was sponsored by the Narragansett Bay Project and was included as part of a bay-wide survey conducted in August 1988 (SAIC, 1989). Dissolved oxygen concentration and the distribution of *Clostridium perfringens* (an indicator of organic enrichment) were also examined as part of this survey. Fifty-nine stations were visited, including three located within Allen Harbor (although not coincident with the established stations). Of these three, two stations were located within the harbor proper (designated in SAIC, 1989, as AH1 and AH2), with the other near the mouth of the harbor (AH3).

Water Column Effects

The assessment of water column effects centered around examining the physiological status and immunological response of deployed *Mytilus edulis*. This bivalve has been used extensively and effectively in the analysis of water quality (e.g., Goldberg et al., 1978; Phelps and Galloway, 1980; Nelson et al., 1987), as it serves as an integrator of temporal variation in waterborne contaminant concentration. Mussel deployment methods were outlined in the Exposure Assessment.

Deployed Mussel Physiological Condition. The physiological status of mussels deployed within Allen Harbor (AH5), immediately outside the harbor at TTN2, and at the bay stations MV and LAB was determined following deployments in the spring (May–June) and fall (September–October) of 1989. Clearance rate, respiration rate, and absorption efficiency were determined in the laboratory following 28-day

exposures. The methods used to establish these parameters are well documented in Nelson et al. (1987), so are described only briefly here.

Physiological measurements were made on two individual mussels of similar size from each of the four replicates per station. Clearance rate was determined by isolating mussels into individual flow-through chambers provided with a unicellular alga of known density to enhance physiological performance. Algal density changes were monitored by taking three hourly measurements from the influent and effluent water streams of each chamber. Algal density was quantified with a Model TAII Coulter Counter. Respiration rate was measured by isolating each individual in a glass respirometer, and monitoring oxygen decline was measured with a Radiometer oxygen meter (Model PHM71). Routine metabolic rate was ensured by acclimating the mussels to the chamber before measurement. Appropriate food was supplied during this acclimation period. Assimilation efficiency was quantified by collecting fecal material following controlled feeding conditions. The ash-free dry weight–dry weight ratio of this material was compared with that of the algal food, and efficiency was calculated as in Conover (1966).

These parameters were used to calculate Scope for Growth (SFG), an integrated index of physiological well-being (Warren and Davis, 1967). Variation in SFG has been correlated with environmental conditions, including contaminant concentration, in Narragansett Bay (Widdows, Phelps, and Galloway, 1981) and in Long Island Sound (Nelson et al., 1987). SFG (in J/h) was calculated as

$$SFG = (C \times A) - R$$

where
C = energy assimilated (J/h)
A = assimilation efficiency (%)
R = energy lost through respiration (J/h)

Differences among stations were identified by using an analysis of variance (ANOVA).

Deployed Mussel Immunological Response. The immunological responses of deployed *Mytilus* were examined by using the phagocytic index assay, a biomarkers procedure under development at ERLN. Marine organisms inhabiting chemically contaminated areas have been observed to have an increased incidence of disease, an increased susceptibility to pathogenic organism attack, and a suppressed phagocytic

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capability (Sinderman, 1984; Fries and Tripp, 1976; Robohm and Nitkowski, 1974). Because phagocytic responses are essential for healthy immunological resistance, decreased phagocytic activity could indicate chronic, sublethal immunological deficiencies.

Blue mussels were deployed adjacent to the landfill in Allen Harbor and at LAB for 28 days by using the methods described previously. Three sets of five mussels were retrieved from each site. Individuals lengths were measured, and the shells were cleaned with 70% ethyl alcohol. Hemolymph (0.1 ml) was extracted from the heart by inserting a 20-gauge hypodermic needle, fitted to a 1-ml tuberculin syringe, through the shell hinge of each animal. The syringe contained 0.9 ml of 30-ppt sterile filtered seawater. Hemocyte suspensions from each animal were placed on cell culture slides treated overnight with poly-l-lysine. Hemocyte counts were made with a hemocytometer.

Phagocytic activity was determined by exposing each hemocyte suspension to a bacterial suspension of *Vibrio alginolyticus* in seawater which had been adjusted to a concentration 10 times that of the hemocyte suspension. The two suspensions were mixed in equal volumes, incubated for 90 minutes, and washed with fresh filtered seawater. Attached cells were stained sequentially with acridine orange and crystal violet for 1 minute. Following a final rinse in fresh sterile seawater, the slides were coverslipped and sealed with hot wax. For each animal sampled, an ultraviolet (UV) microscope was used for duplicate counts of active phagocytic cells among 100 hemocytes. Station differences were determined by using ANOVA.

GENERAL CHEMICAL ANALYSIS

Samples of several environmental matrices were analyzed chemically as part of Waste Site Characterization and Exposure and Effects Assessment exercises. These included both intertidal and subtidal sediments, bivalve and polychaete soft tissues, and whole water from landfill seeps, test pits and wells. Additionally, the dissolved and particulate phases of large-volume water column samples were analyzed for selected contaminants. Descriptions of the strategies, methods, and procedures used in the collection of these samples were provided earlier in this document. The organic and inorganic analysis methods used to quantify contaminant concentrations in the environmental samples are detailed here.

Organic Analysis Methods

The overall flow of organic sample preparation and analysis used in this study is illustrated in figure 7. Extraction schemes were determined by sample type (e.g.,
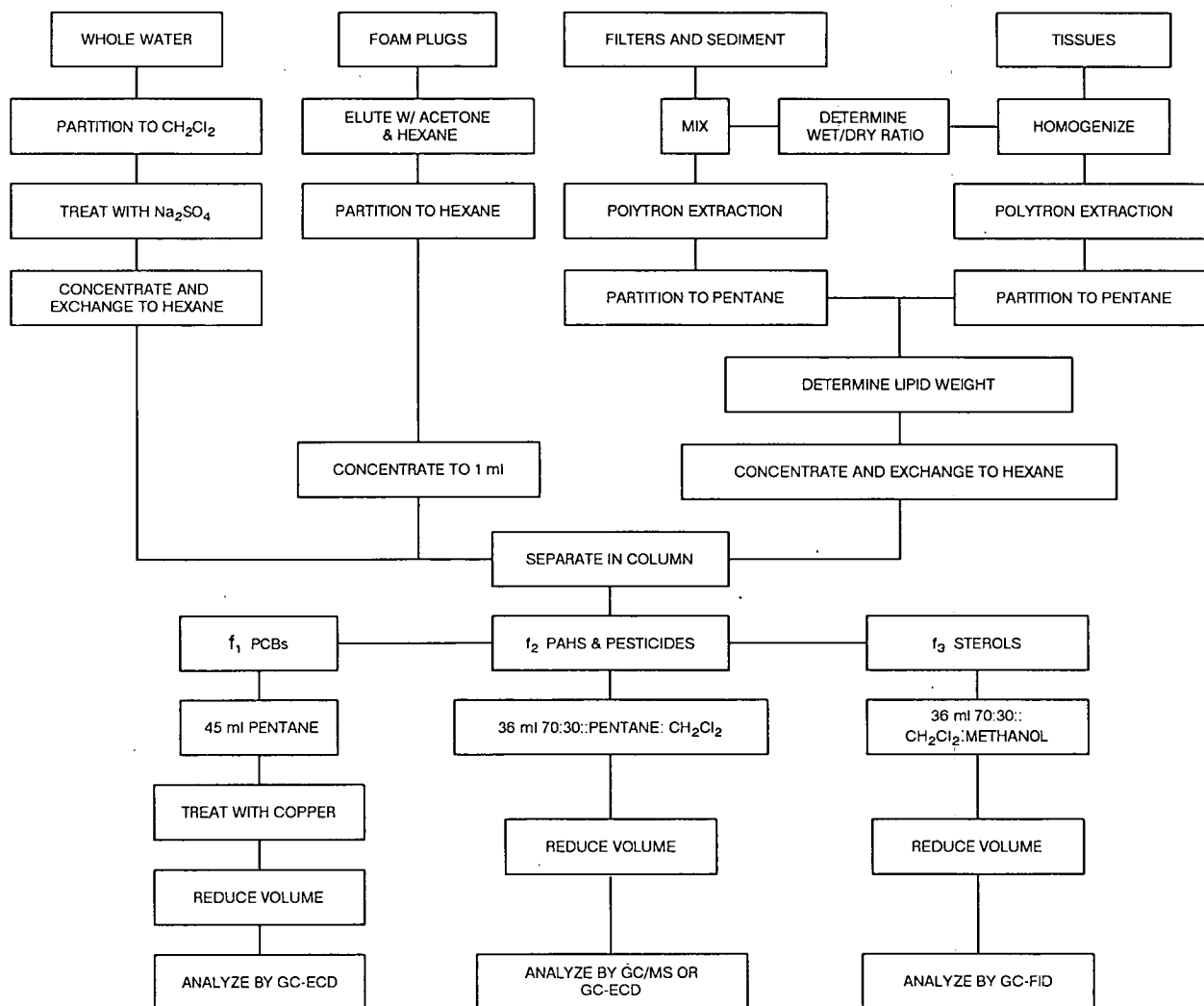
Figure 7. Organic sample preparation and analysis flow chart.

sediment, tissues, water, or foam plugs) and are described first. Subsequent steps common to all sample types, such as column chromatography chemical class separation methods, follow these specific descriptions.

Organic Extraction Procedures. Organic extraction comprised tissue sample extraction, seep and well whole water sample extraction, dissolved water fraction extraction, and sediment and particulate water fraction extraction.

Tissue Sample Extraction. Tissue samples were homogenized with a Polytron homogenizer, and an aliquot was taken for a wet–dry weight determination (dried at 25°C to a constant weight). An aliquot of the remaining tissue homogenate was added to a centrifuge tube along with appropriate internal standards (see below) and 50 ml of acetonitrile. The solvent and sample were mixed with a Polytron homogenizer for 20 seconds. The sample was centrifuged and the supernatant decanted into a separatory funnel containing 300 ml of deionized water. This procedure was repeated two additional times, using 50 ml of acetonitrile each time, and the extracts were combined in the separatory funnel. The acetonitrile-water mixture was extracted three times with 50 ml of pentane each time and the extracts were combined. Anhydrous sodium sulfate (previously baked at 450°C for 16 hours) was added to remove traces of water, and the sample was volume-reduced to 10 ml in a round bottom flask fitted with a Kuderna-Danish evaporator and a three-ball Snyder column. The sample was transferred to a 10-ml graduated concentrator tube containing an ebullator and fitted with a micro-Snyder column and was volume-reduced to 1 ml by using a tube heater. This extract was subjected to chemical class separation by using silica gel column chromatography, as described below.

Seep and Well Whole Water Sample Extraction. The whole water samples were combined in 2-l separatory funnels with appropriate internal standards and extracted with 50 ml of methylene chloride. The CH_2Cl_2 was removed to a flask and the original sample was extracted twice more with 50-ml volumes of CH_2Cl_2. If phase separation was inadequate, the CH_2Cl_2–water emulsion was drawn off into a solvent-rinsed glass centrifuge tube and centrifuged to separate the layers. The combined methylene chloride extracts were then dried over anhydrous sodium sulfate overnight. Dried extracts were carefully decanted to a round bottom flask and volume-reduced as described previously. The extracts were stored under refrigeration at 4°C before chemical class separation by silicic acid column chromatography.

Dissolved Water Fraction (Foam Plug) Extraction. Dissolved organic contaminants in water samples were isolated onto polyurethane foam plugs during field collection procedures. They were subsequently extracted by passing two 50-ml washes of acetone, followed by two 50-ml washes of hexane, through the Teflon housing containing the foam plugs. The extracts were combined in a separatory funnel containing 150 ml of hexane-extracted deionized water. The appropriate internal standards were then added. After shaking and settling, the hexane layer was removed to a flask. An additional 100 ml of hexane was added to the separatory funnel, and the process was repeated. The combined hexane extracts were volume-reduced, as previously described and refrigerated at 4°C until the silicic acid column chromatography step for chemical class

separations. It should be noted that these extracts were not treated with sodium sulfate to remove water.

Sediment and Particulate Water Fraction (Filter) Extraction. Samples of bedded and suspended sediment were extracted in similar fashion. Suspended sediments in large-volume water column samples had been collected onto 0.3-μm glass fiber filter pads, as described previously. Sediment samples were thoroughly homogenized, and a portion of the sample was removed for wet–dry weight determination. About 5–10 grams of the sediment sample, or the entire filter in the case of suspended sediment samples, was added to a stainless steel centrifuge tube along with internal standards and 50 ml of acetonitrile. This suspension was sonicated for 60 seconds with an ultrasonic probe and centrifuged, and the supernatant was decanted into a separatory funnel containing 300 ml of deionized water. This procedure was repeated twice, 50 ml of acetonitrile being used each time, and the extracts were combined in the separatory funnel. The acetonitrile–water mixture was extracted three times with 50 ml of pentane each time, and the extracts were combined. Sodium sulfate was added to remove traces of water, and the sample was volume-reduced and prepared for silica gel chromatography, as described below.

Chemical Class Separation Procedures. Extracted organic samples were separated into three fractions containing distinct classes of contaminants. Contaminants quantified in each fraction are given in tables 1 and 2. Class separations were achieved on a 0.9 × 45-cm column containing 11.5 gram of BioSil A silicic acid (100–200 mesh) that was fully activated and then 7.5% deactivated with water. This deactivation was done by adding an appropriate amount of water to the silica in a glass bottle and placing the bottle on a ball-mill tumbler overnight. Before samples were added, the column was cleaned with 50 ml of methylene chloride and 50 ml of pentane.

All sample extracts were added to the separation column in 1 ml of hexane and were followed by an additional container rinse of 1 ml of hexane. The first fraction (f_1), containing PCB and pesticide compounds, was eluted from the column with 45 ml of pentane. A second fraction (f_2), containing slightly polar compounds such as PAHs, was eluted with 36 ml of 30% methylene chloride in pentane. The third fraction (f_3), containing sterols, was then eluted with 36 ml of 30% methanol in methylene chloride. Activated copper powder was added to the f_1 fraction of sediment samples to remove any free elemental sulfur. The volume of each fraction was then reduced in a round bottom flask by a heating mantle and a Kuderna-Danish evaporator with a three-ball Snyder column. The sample was solvent exchanged into approximately 5 ml of hexane and transferred to a 10-ml concentrator tube fitted with a micro-Snyder column. An ebulator and 0.8 ml of heptane were added to each tube, and the volume was reduced to 0.8 ml by a tube heater. The ebulator was removed and rinsed into the sample, and heptane was used to increase the sample volume to 1 ml.

Table 1. Organic compounds quantified in environmental samples.

Fraction	Compound	Abbreviation Used in Text
f₁	hexachlorobenzene	HCB
	p,p'-dichlorodiphenyl dichloroethene	DDE
	2,2',5,5'-polychlorinated biphenyl	PCB
	2,2'4,4'-PCB	
	2,2'4,5,5'-PCB	
	2,2'3,5,5',6-PCB	
	2,3',4,4',5-PCB	
	2,2',4,4',5,5'-PCB	
	2,2',3,4,4',5'-PCB	
	2,2',3,3',4,4'-PCB	
	2,2',3,4,4',5,5'-PCB	
	2,2'3,3'4,4',5,6-PCB	
	2,2',3,3',4,4',5,5'-PCB	
	2,2',3,3',4,4',5,5',6-PCB	
	C110-PCB	
	Aroclor 1242	A1242
	Aroclor 1254	A1254
	Total PCB	TOTPCB
f₂	a-hexachlorocyclohexane	a-BHC
	g-hexachlorocyclohexane	g-BHC
	a-chlordane	a-CHLOR
	g-chlordane	g-CHLOR
	p,p'-dichlorodiphenyldichloroethane	DDD
	p,p'-dichlorodiphenyltrichloroethene	DDT
	polycyclic aromatic hydrocarbons – see table 2	PAHs
f₃	coprostanol	COPROS
	cholesterol	CHOLR
	cholestanol	CHOLN

Table 2. Polycyclic aromatic hydrocarbons (PAHs) and related compounds quantified in environmental samples.

Fraction	Compound	Abbreviation Used in Text
f_2	fluorene	
	phenanthrene	PHEN
	anthracene	
	C1 homologs of phenanthrene and anthracene	
	C2 homologs of phenanthrene and anthracene	
	C3 homologs of phenanthrene and anthracene	
	C4 homologs of phenanthrene and anthracene	
	fluoranthene	
	pyrene	
	benz[a]anthracene	
	chrysene	
	sum of benzofluoranthenes	
	benzo[e]pyrene	
	benzo[a]pyrene	B(a)P
	perylene	
	indeno[1,2,3-cd]pyrene	
	benzo[ghi]perylene	
	sum of molecular weight 276 PAHs	
	dibenz[a,h]anthracene	
	sum of molecular weight 278 PAHs	
	coronene	
	sum of molecular weight 302 PAHS	
	10-benzotriazole	
	chloro-benzotriazole	
	Sum of parent PAHs	PSUM

Instrumental Analysis.

Gas Chromatography. The f_1 fractions were analyzed for PCBs, HCB, and DDE by capillary gas chromatography (GC). For these analyses, a 1-µl splitless injection was made into a Hewlett Packard 5890 gas chromatograph equipped with a 30-meter DB-5 fused silica capillary column (J & W Scientific) and an electron capture detector. Helium was used as the carrier gas at a flow rate of about 1.5 ml/m; the flow of a 95:5 mixture of argon:methane to the detector was 35 ml/m. The oven temperature was held at 60°C for 1 minute and then ramped from 60 to 315°C at 10°C/min. The injector temperature was held at 270°C, and the detector was maintained at 325°C.

PCBs were quantified as Aroclors 1242 and 1254. A sum of the concentrations of these yielded a measure of total PCBs. In addition, thirteen individual PCB congeners were quantified. These included at least one compound from each chlorination level, ranging from tetrachlorobiphenyls to decachlorobiphenyl. The congener data, although not included in this report, are available by contacting the senior author.

Chlorinated pesticides including hexachlorocyclohexanes, chlordanes, DDD, and DDT were quantified in the f_2 fraction. This fraction was analyzed by capillary gas chromatography with electron capture detection (ECD). The instrument conditions used were the same as those used for the analysis of the f_1 fractions.

The f_3 fractions were analyzed for sterols by capillary gas chromatography with flame ionization detection (FID). The instrument operating conditions were the same as for the f_1 and f_2 fractions, except that the oven temperature was ramped from 150 to 315°C at 10°C/min with no initial hold.

For all of the gas chromatography analyses, analog data from the instruments were digitized with a Perkin Elmer LCI-100 integrator and sent to a Perkin Elmer 3200 Laboratory Information Management System (LIMS) computer. Perkin Elmer Chromatography Laboratory Automation System (CLAS) software was used for selecting peaks and calculating concentrations. Results were stored on the LIMS, and after QA checks, the data were shipped to the laboratory's central VAX 11/785 computer system.

Gas Chromatography–Mass Spectrometry. The f_2 fractions were also analyzed for selected PAHs. These were quantified with a Finnigan 4531 quadrupole gas chromatograph–mass spectrometer (GC–MS) and related peripherals. The Finnigan GC was operated with a capillary column in the splitless injection mode. Each injection consisted of approximately 1 μl of sample extract and 2 μl of solvent backflush. The split flow was approximately 50 ml/min and the septum sweep flow was approximately 2 ml/min. Both flows were suspended for 1 minute just before the time of injection. The DB-5 fused silica column was 30 meters long with a bore of 0.25 μm and a film thickness of 0.25 μm. The GC oven temperature was held at an initial temperature of 50°C for 2 minutes, programmed to 330°C at 10°C/min, and held for an additional 9 minutes.

The last 40 cm of column passed through the transfer line oven area, which was heated to 300°C, and then to within 1 cm of the source volume in the source area of the MS. The latter was maintained at 150°C. The source was operated in the electron impact mode at 70 eV. The filament emission current was 200 μA, and the various source potentials were adjusted to produce a spectrum of decaflurotriphenylphosphine (DFTPP) which met the specifications detailed by Eichelberger, Harris, and Buddle (1975). The MS was scanned from 15 to 650 amu in 1 second while collecting 10 centroid samples per peak. The continuous dynode electron multiplier was operated near 1000 volts, and the preamplifier sensitivity was set to 10^{-8} A/V.

The mass scale of the MS was calibrated by emitting perflurotributylamine into the source, acquiring data, and running a software calibration routine. On each day that samples were analyzed, a solution of standards was also analyzed to enable a determination of the response and retention time of the standards and the spectrum of the DFTPP. If any of these determinations were outside of predetermined limits, remedial action was taken, such as retuning the instrument or reinjecting the standards. After each run, major peaks were checked to ensure that the signal strength was adequate and that no saturation had occurred. After all the samples for the day had been run, another standard run was made to monitor instrument performance.

Areas were manually integrated by using peaks displayed as extracted ion current profiles (EICPs). This permitted a QA check that the compound eluted at the correct time and was free of interferences. For each sample and standard run, a quantitation list (QL) was compiled. The QL contained the areas of the various peaks of interest as determined from their respective EICPs.

Quantitation was done by the method of internal standards (ISs). Two ISs, D_{10}-phenanthrene and D_{12}-benz[a]anthracene, were added to the samples just before extraction. The standard solution also contained the two ISs. Standards runs were used to determine relative response factors (RRFs); i.e., RF of the standard divided by RF of the IS, where RF is the response factor and is defined as the area counts of the peak divided by the amount (in nanograms) injected. Actual concentrations of specific compounds in the sample were then calculated by using the RF of the IS in the sample itself, the area of the compound in the sample, the known amount of IS added to the sample, and the dry weight of the original sample. These calculations were performed in Fortran with a LIMS computer, after the QLs had been transmitted from the Nova 3 to the LIMS via an RS232 data line.

After the calculations were made, a plot of the concentrations of selected compounds versus molecular weight was examined for obvious anomalies. Only after this QA step were the data added to the permanent databases resident on the LIMS and VAX computers. The raw GC–MS data were archived on industry standard magnetic tapes.

Volatile Organic Sample Analysis. Volatile organic analyses were performed by J. Quinn at the University of Rhode Island Graduate School of Oceanography. Samples were stored in 40-ml glass vials at 4°C before analysis. Quantification was performed on a Tracor model 540 GC equipped with a photoionization detector (PID), a hall detector, and a Tracor LSC-2 sample concentrator. Samples were purged for 12 minutes with helium at a flow rate of 40 ml/minute. Volatile hydrocarbons were collected on a tenax/silica gel trap, which was then thermally desorbed at 180°C onto a 30-meter DB-624 fused silica capillary column (3-μm film, 0.53-mm i.d.). The GC

was temperature programmed from 35 to 140°C at 6°C/min. Results were quantified with a Spectra Physics model 4270 integrator.

The volatile organic compounds quantified in this study are listed in table 3. A standard solution containing these compounds was injected before the analyses to calibrate the instrument and generate response factors. All reported values were corrected for blanks, which were typically <5% of the lowest reported concentration. The precision of the method was determined to be ±5% based on replicate injections. All samples were analyzed in duplicate. The detection limit for all volatile organic compounds was 0.1 ppb.

Table 3. Volatile organic compounds (VOCs) quantified in environmental samples.

Compound	
vinyl chloride	trans-1,3-dichloropropene
1,1-dichloroethene	1,1,2-trichloroethane
methylene chloride	tetrachloroethene
trans-1,2-dichloroethane	dibromochloromethane
1,1-dichloroethane	chlorobenzene
cis-1,2-dichloroethane	bromoform
chloroform	1,1,2,2-tetrachloroethane
1,1,1-trichloroethane	1,3-dichlorobenzene
carbon tetrachloride	1,4-dichlorobenzene
1,2-dichloroethane	1,2-dichlorobenzene
trichloroethene	methyl-t-butyl ether
1,2-dichloropropane	benzene
bromodichloromethane	toluene
2-chloroethylvinyl ether	ethylbenzene
cis-1,3-dichloropropene	m,p-xylene
	o-xylene

Quality Assurance—Organic Analysis. Numerous quality control steps and quality assurance checks were performed during all phases of organic chemistry analysis. In addition to those described in the analytical procedures presented above, a more generic description is provided here.

All glassware used for sample analysis was washed with Alconox and rinsed with tap water and deionized water. The glassware was capped with aluminum foil, muffled at 450°C for 6 hours, and stored capped with foil. Immediately before use, each item was uncapped and rinsed with an appropriate solvent.

Blank analyses were conducted with each set of samples. On average, this amounted to one blank analysis for every 6 samples. None of the blanks analyzed in this study contained significant amounts (more than 10% of the lowest measured concentration) of the compounds of interest.

Consistent silicic acid column activity was assured by testing each batch. A mix of PCB and PAH isomers was separated on a column made up of the newly deactivated silica, and the relative distributions of compounds in the column fractions were monitored.

Extraction efficiency was assured by conducting spike and recovery studies. The first study was conducted by spiking a homogenate of clams collected from a known unpolluted area with representative compounds from each of the chemical classes studied. The spiking levels chosen were similar to those anticipated in samples from moderately contaminated sites. Thirteen PCB congeners, 8 chlorinated pesticides, and 12 PAH isomers were spiked into three clam homogenate samples. Background levels of these compounds were measured in two unspiked homogenate samples and were subtracted. A reagent blank was also analyzed in parallel. The results of this QA check indicated overall recoveries of 74 ± 8% for PCB congeners, 74 ± 10% for chlorinated pesticides, and 60 ± 7% for PAH isomers. These results represent absolute recoveries for these compounds. However, all of the quantitations of organic compounds were done by the internal standard method. Therefore, the results were automatically corrected for losses in the analytical procedure. Octachloronaphthalene was used as the internal standard or surrogate compound for PCBs, gama-chlordene was used for chlorinated pesticides, and D_{10}-phenanthrene and D_{12}-benz[a]anthracene were used as PAH surrogates.

A second spike and recovery study was performed as a quality assurance check for the coprostanol analysis method. For this, two aliquots of a well-characterized sediment from a relatively uncontaminated location were spiked with coprostanol, and its recovery through the analytical procedure was measured. Recoveries were measured at 83 and 86%. The surrogate compound used for quantitation of coprostanol was 7,(5a)-cholesten-3B-ol.

By convention, concentrations below the analytical detection limits of this study are reported as 0.00 or as "nd" (not detected). Actual analytical detection limits differed for each compound and each sample. Differences across compounds were due to differences in the instrumental response factors of each compound. Variation across samples was due to differences in the amount of sample analyzed and the levels of

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interfering compounds in the extracts. By using the instrumental detection limit for each compound and the final volume of the extracts, one could calculate the approximate detection limits in the extract for each compound or class of compounds (table 4). When divided by the original dry weight of the sample analyzed, these limits were used to derive approximate analytical detection limits (e.g., the analytical detection limit for Aroclor 1242 in 5 grams of dry sediment was 9 ÷ 5 = 1.8 ng/g).

Table 4. Realized extract detection limits for organic contaminants.

Compound	Extract detection limit (ng)
Aroclor 1242	9
Aroclor 1254	13
PCB congeners	0.59 – 1.60
chlorinated pesticides	0.11 – 0.77
PAHs	0.50 – 2.0
sterols	1000

Analytical precision or instrumental variability was determined by replicate injections of the same standard or sample. Instrumental variability for all organic components measured ranged between 1 and 8% RSD (relative standard deviation, equivalent to the coefficient of variation). Sample preparation and analysis variability was further determined by producing three replicates of a sample and injecting each separately. This variation ranged between 10 and 20% RSD. Analytical accuracy was determined by the analysis of standard reference materials (SRMs). These were either produced in-house, as in the case of a so-called "Mega-Mussel-Mush," or were obtained from commercial sources such as the National Institute of Standards and Technology (NIST) or the National Research Council of Canada (NRCC). The repeated analysis of in-house SRMs has established concentrations of organic analytes, and certified values exist for the commercial SRMs, permitting a check on the accuracy of concentrations determined for environmental samples. Generally, the accuracy of organic methods was ± 25% of the accepted value for the SRM. When observed sample concentrations were outside these limits, remedial action was taken (including reinjection, reextraction, or instrumental repairs or replacements). The frequency of analysis of replicates and SRMs was approximately 5%, or one SRM and one triplicate per 20 samples analyzed.

Inorganic Analysis Methods

Sample preparation and analysis methods for inorganic determinations varied not only with sample matrix, but also with the compound to be quantified. Figure 8 illustrates the general sample preparation and analysis scheme used for most inorganic compounds. There were differences in procedures for the remaining two metals,

mercury and arsenic. Data generated during the preparation of samples were manually entered into a computerized database for subsequent analyses and calculations. Table 5 lists the inorganic compounds examined in this study.

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┌─────────────────────┐      ┌─────────────────────┐                        ┌─────────────┐
│ WHOLE WATER &       │      │ PARTICULATE FRACTION│                        │   TISSUES   │
│ SOLUBLE FRACTION    │      │ & SEDIMENT          │                        │             │
└─────────┬───────────┘      └─────────┬───────────┘                        └──────┬──────┘
          │                            │                                           │
┌─────────┴───────────┐      ┌─────────┴───────┐  ┌───────────────┐  ┌─────────────┴──┐
│   ACIDIFY TO pH 2   │      │   HOMOGENIZE    │──│ WEIGH ALIQUOT │──│   HOMOGENIZE   │
└─────────┬───────────┘      └─────────┬───────┘  └───────────────┘  └─────────┬──────┘
          │                            │                                           │
┌─────────┴───────────┐      ┌─────────┴───────┐  ┌───────────────┐  ┌─────────────┴──┐
│ COPRECIPITATE WITH  │      │   FREEZE DRY    │──│ WEIGH SAMPLE  │──│  FREEZE DRY    │
│   APDC AND CO       │      └─────────┬───────┘  └───────────────┘  └─────────┬──────┘
└─────────┬───────────┘                │                                           │
┌─────────┴───────────┐      ┌─────────┴─────────────┐             ┌─────────────┴───────┐
│   FILTER AND        │      │ ULTRASONICATE WITH    │             │ DIGEST IN MICROWAVE │
│   DISCARD LIQUID    │      │ 2N HNO₃               │             │ W/ CONC. HNO₃       │
└─────────┬───────────┘      └─────────┬─────────────┘             └─────────────┬───────┘
┌─────────┴───────────┐      ┌─────────┴─────────────┐             ┌─────────────┴───────┐
│   ELUTE WITH        │      │ CENTRIFUGE AND        │             │ FILTER AND          │
│   2N HNO₃           │      │ SAVE SUPERNATANT      │             │ DISCARD PARTICULATES│
└─────────┬───────────┘      └─────────┬─────────────┘             └─────────────┬───────┘
┌─────────┴───────────┐      ┌─────────┴─────────────┐             ┌─────────────┴───────┐
│   ANALYZE BY        │      │   ANALYZE BY          │             │   ANALYZE BY        │
│   HGA-AA            │      │   ICP OR HGA-AA       │             │   ICP OR HGA-AA     │
└─────────────────────┘      └───────────────────────┘             └─────────────────────┘
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Figure 8. Inorganic sample preparation and analysis flow chart.

Table 5. Inorganic compounds quantified in environmental samples.

Compound	Abbreviation Used in Text
copper	Cu
zinc	Zn
chromium	Cr
lead	Pb
nickel	Ni
cadmium	Cd
manganese	Mn
iron	Fe
silver	Ag
mercury	Hg
arsenic	As
monobutyltin*	MBT
dibutyltin*	DBT
tributyltin*	TBT

*Analyses performed by NOSC.
See text for preparation and analysis procedures.

Inorganic Extraction Procedures.

General Tissue Sample Preparation. Whole organisms were thawed, and if necessary, separated from the shell with stainless steel instruments. As a precaution against cross-contamination, instruments were cleaned between samples by rinsing them with deionized water. The tissues were homogenized in a titanium homogenizer and aliquots (approximately 15 grams) were placed in tared, acid cleaned, Teflon digestion vessels. After wet weights were determined, samples were freeze-dried under vacuum for 48 hours at $-40°C$, and then heated for 24 hours at $45°C$. Fifteen ml of concentrated nitric acid (HNO_3, Instra-Analyzed grade) was added to each sample vessel after dry-weight determination.

The tissues were digested by microwave (see Kingston and Jassie, 1986; Nakashima et al., 1988; Patterson, Veillon, and Kingston, 1988) in open vessels to reduce residual organic material. Typical digestions lasted for 13 minutes at power settings dependent on the number of samples being processed. After cooling, samples were vacuum-filtered through acid-washed ($2N$ HNO_3) Whatman 42 filter paper. The digestion vessel and filter apparatus were rinsed with deionized water, and the combined filtrates were diluted with deionized water to a volume of 50 ml in a volumetric flask. Sample solutions were stored in 60-ml acid-cleaned, polyethylene bottles before analysis.

Mercury and Arsenic Tissue Sample Preparation. The preparation of tissues for mercury and arsenic analyses differed from the above procedure in that samples were not dried before acid digestion. Dry weights for these samples were calculated from the measured wet weights and the dry weight-to-wet weight ratios obtained from the corresponding trace metal samples. Additionally, a two-step digestion was used for these analyses. The first step involved microwave digestion as described above, by means of both nitric acid and hydrogen peroxide (H_2O_2). After filtration and dilution to 50 ml, 5-ml aliquots of each sample were removed to borosilicate scintillation vials and evaporated to near dryness in a heating block at $50°C$. H_2O_2 was added to each vial slowly to prevent foaming and again evaporated to near dryness. Nitric acid was added to each sample, which was subsequently ultrasonicated for 1 hour. This step was necessary to decompose organic matter and surface-active compounds which cause foaming and interferences in the hydride reaction step of the mercury analysis (see below). Samples were stored in the scintillation vials before analysis.

General Sediment Sample Preparation. Sediment samples were thawed completely and homogenized by stirring with a stainless steel spatula. Aliquots of wet sediment (approximately 2.5 grams) were transferred to tared, acid cleaned, 125-ml polycarbonate centrifuge tubes, and wet weights were determined. The aliquots were refrozen and freeze-dried in a Virtis lyophilizer (Model No. 10-145MR-BA) for 16 hour at $-40°C$, followed by heating at $45°C$ for 24 hours. Dry weights were determined and the dried samples acidified with 20 ml of $2N$ HNO_3 (Instra-Analyzed grade). The

centrifuge tubes were then placed in an ultrasonic bath and sonicated overnight (approximately 16 hours), during which time the temperature of the water bath was increased to about 75°C. Samples were reweighed following their removal from the water bath and cooling and were centrifuged at 10,000 rpm for 15 minutes. The supernatant was decanted into a 25-ml volumetric flask. An additional 5 ml of nitric acid was added to the residue which was again ultrasonicated for 15 minutes. Following recentrifugation, the resulting supernatant was added to the volumetric flask. Additional nitric acid was added, and the samples were transferred to acid-cleaned 60-ml polyethylene bottles for storage before analysis.

Mercury and Arsenic Sediment Sample Preparation. The sediment samples for mercury and arsenic analyses were prepared differently from the above approach only in that samples were not freeze-dried. Dry weights for these samples were calculated from wet weights, and dry weight-to-wet-weight ratios were obtained from corresponding trace metal samples.

General Whole Water Sample Preparation. Whole water samples obtained from landfill seeps and wells were acidified to a pH of approximately 2 with 1 μl of concentrated HNO_3 per milliliter of sample. The samples were shaken and allowed to settle for at least 1 hour to recover particulate metals and metals adsorbed to the container walls. One ml of each sample was transferred to an acid-cleaned polyethylene vial, and 100 μl of concentrated nitric acid was added to each. The vials were capped, shaken well, and stored for future analysis.

Sediment and Tissue Extraction for Butyltin Compounds. Following homogenization of samples in preparation for organic or inorganic analysis, approximately 30 grams of homogenate was removed for butyltin analysis. This homogenate was placed in polycarbonate bottles and shipped on ice to the NOSC facility in San Diego, California, where the analyses were performed. Samples were stored at –6°C before analysis.

The method involved a Grignard derivatization of the samples as described by Stallard, Cola, and Dooley (1989). Samples were thawed and rehomogenized, placed in tared polypropylene centrifuge tubes, and weighed. A separate aliquot was removed for dry weight determination; this material was dried overnight at 100°C in tared aluminum pans and weighed. Ten ml of 50% (by volume) hydrochloric acid was added, and each sample was vortexed for 2 minutes. Following a half hour of particle settling, 20 ml of methylene chloride was added and the sample was revortexed. Samples were then placed on a reciprocating shaker for 3 hours. After the samples were centrifuged for 10 minutes at 4000 rpm, a 2-ml aliquot of the CH_2Cl_2 was removed for derivatization and dried under air at 35°C.

Tripentyltin bromide was added as an internal standard to each sample, which was then reconstituted in hexane. One quarter ml of 2M n-hexylmagnesium bromide was added as the Grignard reagent. After 15 minutes, any remaining Grignard reagent was

destroyed by the addition of sulfuric acid, followed by vortexing. Samples were then centrifuged, and the organic layer was removed and passed through SUPELCO florisil columns for cleanup. Extracts were dried and reconstituted with hexane before instrumental analysis.

Instrumental Analyses

ICP Analysis. Trace metal determinations for most sediment and organism samples were performed on an ARL 3410 inductively coupled plasma (ICP) emission spectrometer. This instrument was operated under the standard conditions recommended by the manufacturer and was calibrated with standard solutions before each use. Background shifts and potential spectral interferences were investigated by scanning elemental lines in representative samples. Calibration curves for each element were generated from a series of standard solutions before the analysis of samples and were normalized for instrumental drift. The analytical results were transmitted to the Perkin-Elmer LIMS, where analytical and sample preparation data were used to calculate the concentrations of the metals.

Atomic Absorption Analysis. Samples with low trace metal concentrations (below the detection limits of the ICP; see table 6), and those from the landfill seeps and well, were analyzed by heated graphite atomization (HGA) atomic absorption (AA) by means of a Perkin-Elmer (Model 5000) AA spectrophotometer with Zeeman background correction. The instrumental parameters were based on the manufacturer's recommendations and ERLN SOPs. Working standards were prepared from 1 ml of seawater stripped of metals (with Chelex-100 resin) or from open ocean reference seawater (NASS-1). One hundred μl of concentrated HNO_3 was added and spiked with 5 μl of the appropriate stock solution. Absorbance signals were recorded with a strip chart recorder (Perkin-Elmer Model 56) and collected directly on a data station (Perkin-Elmer Model 3600). Transient signal data were reduced to peak height and area for each sample or element determined. The instrument was calibrated before use and verified after every ten samples. Samples were routinely analyzed three times for each metal to determine signal reproducibility.

Regression curves generated from absorbance data for standards were used to determine concentrations in unknown samples. Polynomial regression algorithms used to calculate standard curves from the absorbance data were described by Rugg and Feldman (1980). Analytical results were transmitted from the data station to the LIMS computer for the calculation of sample concentrations and storage of the data. After additional quality assurance checks, the data were transmitted to the VAX computer. Generally, for each 15 samples processed, one sample was also analyzed by the method of standard addition, and one procedural blank sample was analyzed.

Table 6. Representative detection limits
of inorganic analyses of tissues, water,
and sediments.

Metal	Detection Limit (μg/g)	
	ICP	AA
Cu	0.40	0.01
Zn	0.20	0.10
Cr	0.50	0.01
Pb	0.50	0.10
Ni	0.40	0.02
Cd	0.10	0.003
Mn	0.10	0.005
Fe	0.40	0.01
Hg	0.13	<0.001

Mercury and Arsenic Analysis. Mercury determinations were conducted by the cold vapor technique with a Perkin-Elmer mercury/hydride system (Model MHS-20) equipped with a gold amalgam attachment on a Perkin-Elmer AA (Model 403). Arsenic analyses were performed in a similar manner, except that the gold amalgam attachment was not used. A Perkin-Elmer integrator (Model LCI-100) was used to collect output from the AA and to integrate signal peaks generated by the MHS-20. Peak areas for samples and standards were manually entered into data-reduction programs used for atomic absorption data to determine unknown sample concentrations. Blank determinations and standard additions were performed with each set of samples to check instrument performance.

Butyltin Analysis. A GC/flame photometric detector (FPD) with a Hewlett Packard 5890A GC was used to analyze extracted tissue and sediment samples for butyltin chloride. A five point calibration curve was generated monthly to ensure that the butyltin calibration standards, with tripentyltin bromide as the internal standard, were linear. The response factors of all three analyte species (mono-, di-, and tributyltin chloride) were averaged, with a 95% confidence interval. A daily calibration standard was used to quantify sample concentrations and to monitor daily fluctuations of the instrument.

Sediment samples were analyzed in triplicate to provide an indication of variability. If sample size permitted, tissue samples were analyzed in similar fashion. Instrument detection limits have been established for mono- and dibutyltin species as 0.29 and 0.12 ng, respectively. Concentrations for each tin species are reported in μg/g dry weight based on the measured wet weight-to-dry weight ratios.

Quality Assurance—Inorganic Analysis

Procedural blanks were run with each set of samples and, along with the sample sets were analyzed for metals. Concentrations reported in data presentations are corrected for blank levels when they exceeded detection limits. Representative detection limits, expressed as the equivalent sample concentration for tissues, sediments, and waters, are given in table 6.

For each set of analyses, samples were spiked after analysis with a spike of comparable concentration and were reanalyzed. Spike recovery was calculated from the difference in the concentrations of the spiked and unspiked samples as a percentage of the added spike. Spike recovery indicated the reliability of determining sample concentrations by comparing the sample against aqueous standards and also verified the absence of matrix interferences. The recoveries calculated for the different sets of analyses are given in table 7, as are recoveries as the percentage of the certified value of each metal for tissue and sediment SRMs. An appropriate SRM was analyzed with a frequency of about 5%, or one for every 20 samples of a given matrix. Remedial action in the form of recalibration, reanalysis, or repair of the instrument was taken if the recoveries so warranted.

Table 7. Recovery of standards in inorganic analyses.

Metal	Spike Recovery (percent)		SRM Recovery (percent)	
	Tissues	Sediments	Tissues	Sediments
Cu	86 – 102	52 – 99	80 – 116	97 – 102
Zn	80 – 83	96 – 115	71 – 99	84 – 86
Cr	82 – 95	93 – 106	28 – 89	34 – 41
Pb	64 – 84	103 – 112	88 – 119	74 – 86
Ni	81 – 105	88 – 103	75 – 109	65 – 81
Cd	85 – 91	94 – 106	79 – 103	92 – 111
Mn	87 – 93	87 – 103	81 – 110	53 – 62
Fe	88 – 125	nm*	84 – 101	67 – 72
As	95 – 125	76 – 91	63 – 79	58 – 73
Ag	85 – 112	89 – 136	105 – 141	nm
Hg	52 – 58	72	88	71

*nm = not measured.

Analytical reproducibility was also examined by the analysis of triplicate samples. The frequency of the analysis of triplicates was about 5%. The analytical variability for most metals was in the range of 1–10% RSD, although silver, arsenic, and mercury showed a higher variability.

RESULTS AND DISCUSSION

WASTE SITE CHARACTERIZATION

Historic information collated by TRC-ECI (1986) indicates a range of waste materials to have been deposited in the Allen Harbor landfill (table 8). These include complex organic and inorganic wastes, such as jet fuel, waste oils, and coal ash, as well as organic solvents, asbestos, and sewage sludge. The exact quantities of the wastes deposited are unknown, although in some cases they may have been substantial (table 8). Many of these wastes or their constituents are known toxicants (see Klaassen, Ambur, and Doull, 1986).

Table 8. Anthropogenic wastes reportedly deposited in the Allen Harbor landfill (modified from TRC-ECI, 1986).

Waste Material	Estimated Quantity Deposited
unused paint	6,500 – 13,000 gal
paint sludge	11,700 gal
turpentine and acetone	90 – 180 gal
paint thinner and degreaser	9,600+ gal
trichloroethylene	3,000+ gal
carbon tetrachloride	171,000+ gal
jet fuel	3,300 – 4,950 gal
transformer oil	1,260 gal
mixed petroleum base oil	858,000 gal
P-1 and P-2 preservative	15,125 gal
chromic acid	unknown
sulfuric, nitric, and phosphoric acids	<7,260 gal
misc. plating wastes	39,000 gal
sewage sludge	11,000 – 13,800 yd3
coal ash	unknown
carbide	250 – 300 lb
asbestos	810 – 1,800 ft3
hardened cement	4,042 ton
waste coating materials	83,000 gal
mineral grit	1,100 ton
magnitron tubes	2,000 tubes

The chemical analysis of seep, test pit, and well water samples provided a more direct characterization of wastes potentially affecting the harbor. Flow rates from some landfill seeps were extremely low, precluding the collection of sufficient sample volumes to analyze all classes of compounds. Samples obtained from the south side of

the landfill contained high levels of several chlorinated solvents, including cis- and trans-1,2- dichloroethene and 1,2-dichloroethane (table 9). Methyl-t-butyl ether, toluene, acetone, and methylene chloride were commonly encountered at low levels (Appendix L). All VOC compounds measured were below RIDEM's 1988 Minimum Data Base Guidelines for VOCs in freshwater (table 10). In addition to these compounds, analyses conducted at URI-GSO also suggested the presence in selected seeps of aromatic hydrocarbons derived from petroleum products such as fuel oil, diesel oil, gasoline, and kerosene. A large variation in VOC concentration was observed among seep samples.

Very high levels of total PCBs were measured in seep samples from the south face of the landfill (table 9). The maximum value observed of 1.49 ppb exceeds EPA's marine water quality criterion (WQC) concentration of 0.030 ppb for PCBs (U.S. EPA, 1980). It should be noted, however, that because flow rates from the landfill seeps were minimal, the method of sample collection resulted in the inclusion of relatively large amounts of sediment (approximately 2-5 grams). This material was extracted along with the water, since postcollection filtration would have altered the water chemistry. The quantity of sediment included is typically sufficient for sediment sample analysis. Thus, the non-VOC chemistry results reported for seep waters may in fact reflect the chemistry of landfill sediments. In agreement with this hypothesis is the observation that total PCB levels in seep samples were one to two orders of magnitude higher than the levels measured in ground water samples (see below). PAH levels followed similar trends (table 9).

A comparison of ionic concentrations in seep samples with an open ocean seawater standard (NASS-1) indicated these waters to be approximately 50-80% seawater.* This result suggests that Allen Harbor seawater infiltrates the porous sediments and soils of the landfill on flood tides, and drains from the landfill on the following ebb tides. Despite this, trace metal concentrations observed in seep samples were again very high (table 9), violating the WQC for Cu, Cd, and Pb (table 11). Although no metals data are available for ground water samples for purposes of comparison, these data are probably more indicative of sediment chemistry than of seep water chemistry.

Perched and ground water samples collected in conjunction with TRC-ECI from a single test pit and four wells contained a suite of VOCs which differed in some respects from that observed in seep samples (table 9 and Appendix L). Although elevations in cis-1,2-dichloroethene were observed, trans-1,2-dichloroethene and 1,2-dichloroethane generally were not detected. High levels of chlorobenzene and benzene were present, however. Petroleum hydrocarbons were also present (up to 100-200 ppb) in some samples.

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*W. Boothman, U.S. EPA, personal communication.

Table 9. Maximum contaminant levels observed in landfill seep, pit, and well water.

Compound	Seeps	Test Pit	Wells
cis-1,2-dicholoroethene	170.5 [a]	nd [b]	90.3
trans-1,2-dichloroethene	24.3	nd	0.5
1,2-dichloroethane	101.2	nd	nd
chlorobenzene	0.1	1.9	20.5
benzene	nd	13	3.6
toluene	0.1	0.6	2.0
total PCB	1.49	nm [c]	0.046
total PAHs	25.8	nm	0.549
phenanthrene	0.086	nm	0.088
benzo(a)pyrene	0.185	nm	0.336
HCB	>0.001	nm	nd
Cu	111	nm	nm
Cr	1.25	nm	nm
Pb	57.5	nm	nm
Cd	15.6	nm	nm
As	5.95	nm	nm

[a] Concentrations of all contaminants reported in μg/L.

[b] nd = not detected.

[c] nm = not measured.

As mentioned earlier, total PCB and PAH concentrations were lower in ground water samples than in seep water. PCB levels were still in violation of WQC, however (tables 9 and 11). Pesticides were typically not detected in the ground water.

Activities conducted to identify contaminants within the landfill and at Calf Pasture Point are, as of this writing, insufficient to fully characterize these waste sites. Chemical analyses to be conducted by both ERLN and TRC-ECI are needed to complete the description of the nature and extent of their potential influences upon the Allen Harbor system. This information will be made available in later reports as it is completed.

EXPOSURE ASSESSMENT

Exposure conditions in Allen Harbor were characterized by a combination of physical, chemical, and microbiological measurements made in sediments and the water column. The bioaccumulation of contaminants in indigenous and deployed organisms provided an additional indication of exposure. Following the original sampling design, these data have been viewed in two ways. Station comparisons of contaminant levels

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Table 10. RIDEM 1988 Minimum Database Guidelines for volatile organic compounds in freshwater.

Chemical Group	Compound	Acute (μg/L)	Chronic (μg/L)
Chlorinated benzenes	chlorobenzene	795	18
	1,2,4-trichlorobenzene	75	1.7
	1,2,3,5-tetrachlorobenzene	321	7.1
	pentachlorobenzene	13	0.28
Chlorinated ethanes	1,1,2-trichloroethane	900	20
	1,1,2,2-tetrachloroethane	466	10
	1,2-dichloroethane	5,900	131
	1,1,1,2-tetrachloroethane	980	22
	pentachloroethane	362	8.0
	hexachloroethane	49	1.1
Dichlorobenzenes	1,2-dichlorobenzene	79	1.8
	1,3-dichlorobenzene	390	8.7
	1,4-dichlorobenzene	56	1.2
Dichloropropanes	1,1-dichloropropane	1,150	26
	1,2-dichloropropane	2,625	58
	1,3-dichloropropane	303	6.7
Dinitrotoluenes	2,3-dinitrotoluene	17	0.37
	2,4-dinitrotoluene	1,550	34
Halamethanes	methyl chloride	9,650	214
	bromoform	1,465	33
Others	benzene	265	5.9
	carbon tetrachloride	1,365	30
	1-chloronaphthalene	80	1.8
	chlorform	1,445	32
	1,1-dichloroethylene	580	13
	ethyl benzene	1,600	36
	4-bromophenyl phenyl ether	18	0.4
	naphthalene	115	2.6
	n-nitrosodiphenylamine	293	6.5
	tetrachloroethylene	240	5.3
	toluene	635	14
	trichloroethylene	1,950	43

Table 11. U.S. EPA Marine Water Quality Criteria.

Compound	Chronic Criteria*	Reference
PCB	0.030	U.S. EPA (1980)
Cu	2.9	U.S. EPA (1985a)
Pb	5.6	U.S. EPA (1985b)
Cd	9.3	U.S. EPA (1985c)

*All concentrations reported in $\mu g/L$.

within the harbor provided insight to spatial variability and the location of potential hot spots. Allen Harbor stations were also treated as replicates in comparisons with the Narragansett Bay stations, providing a relative basis for determining potential waste site influences.

The large number of contaminants quantified in this study precludes a specific discussion of all the contaminants measured. In the following discussion, emphasis is placed on a smaller subset of the full list. This subset includes total PCBs (TOTPCB), arsenic (As), chromium (Cr), lead (Pb), copper (Cu), cadmium (Cd), coprostanol (COPROS), benzo(a)pyrene (B(a)P), total parent PAHs (PSUM), and tributyltin (TBT). These particular analytes were chosen because of their known or suspected presence in the landfill, their documented toxicological importance in marine systems, or because of their interesting behavioral patterns. A discussion of the behavior of other contaminants are also included if noteworthy results were obtained. All organic and inorganic chemical data relevant to exposure conditions in Allen Harbor are presented in Appendices F-L.

Sediment Exposure

Granulometry. A large variation was observed in the proportions of sand, silt, and clay among subtidal stations (figure 9). Whereas AH, MV, and PC sediments consisted primarily of clays and silts, GB sediments were greater than 90% sands. NJ sediments were also largely sands. These patterns reflect the depositional and erosional characteristics of each site. For example, Allen Harbor, an enclosed, quiescent body of water, accumulates fine grained sediments. GB, located in a region of relatively high current movement, represents an area of active erosion. These physical characteristics can profoundly affect the chemical and biological attributes of each site.

In contrast to subtidal sediments, sediments collected from intertidal stations were fairly similar in grain size distribution (figure 9). Sand predominated in these samples, perhaps reflecting a similarity in the physical processes active in these areas.

Subtidal sediments at stations within Allen Harbor were dominated by clays and silts (figure 10). Station AH10, near the mouth of the Harbor, exhibited elevated levels

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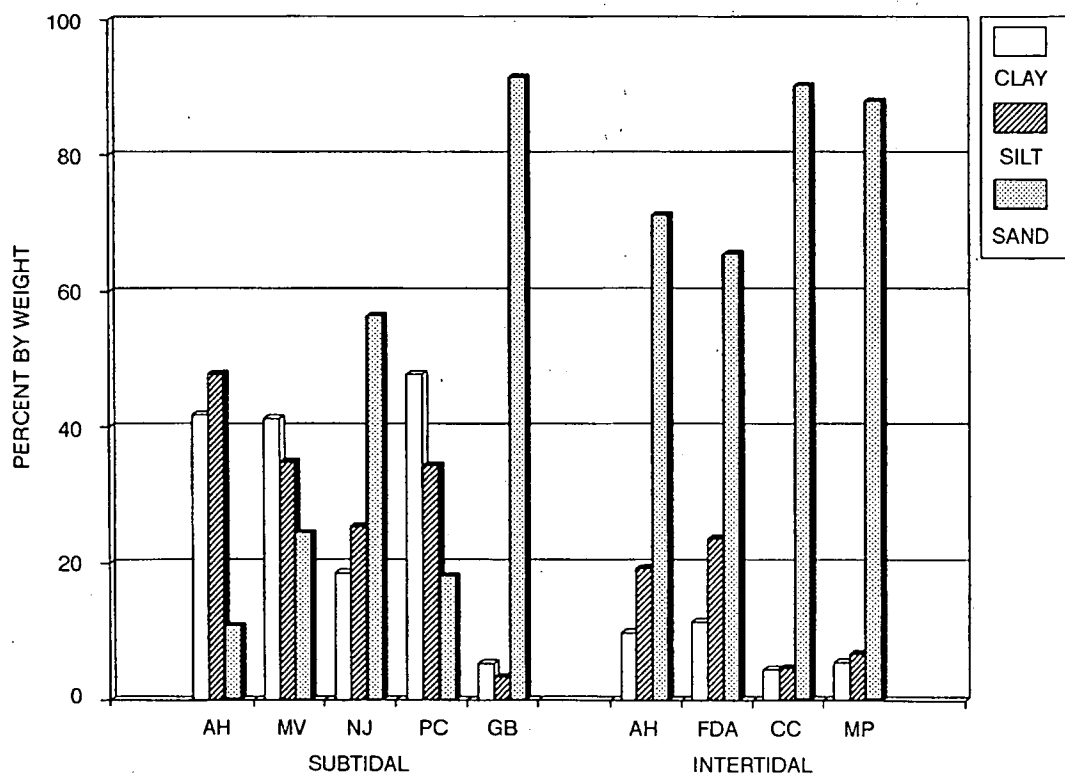
Figure 9. Granulometry of sediments at Narragansett Bay stations.
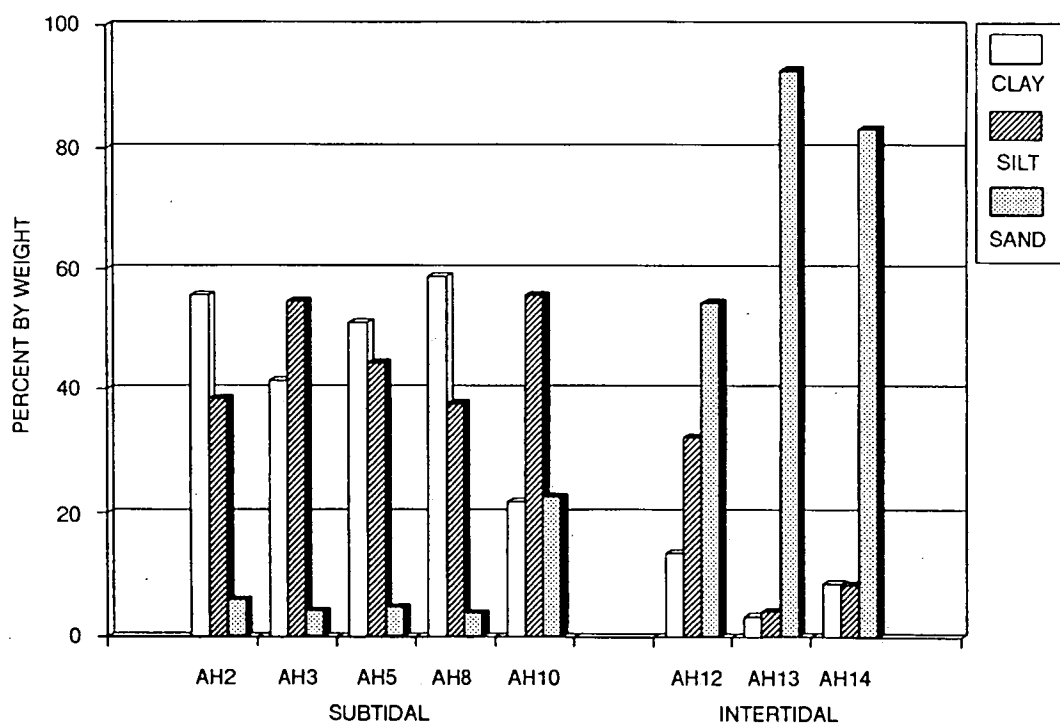
Figure 10. Granulometry of sediments at Allen Harbor stations.

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of sand relative to the remaining stations. Sediments at the Allen Harbor intertidal stations consisted primarily of sand (figure 10).

Chemistry

Subtidal Sediments. Figure 11 shows representative contaminant concentrations observed at the subtidal sediment stations. Because of the large variation observed in grain size distributions among stations, and the potentially confounding influence of grain size differences on measured contaminant levels, statistical comparisons of sediment chemistry included an analysis of covariance (ANCOVA), which treated percent sand as the covariate. These analyses revealed no differences between Allen Harbor and Narragansett Bay stations in pesticide, PCB, or butyltin concentration (table 12). However, differences were found among stations in all inorganic contaminants measured, as well as in sterols and PAHs.

When significant differences among stations were observed, Allen Harbor often fell within the group of stations exhibiting the highest levels (as determined by Tukey's studentized range test; see table 12). Generally, however, PC exhibited the highest concentrations of contaminants. Allen Harbor chemistry was typically most similar to that of Mount View, whereas NJ and GB were least contaminated. Only the pesticide HCB exhibited the statistically highest concentration in Allen Harbor. In no instance were contaminant levels in Allen Harbor significantly lower than those at all other stations (table 12).

The analyses summarized in table 12 indicate that the importance of grain size was limited primarily to inorganic compound concentrations. It is expected that organic carbon would be important in determining organic contaminant distributions (e.g., Karickhoff, Brown, and Scott, 1979). The quantification of this variable in subtidal sediments will be pursued in the future. It is interesting to note that despite the removal of the influence of grain size, trace metal levels were typically highest in PC sediments. This material was skewed toward small particle sizes and contained a relatively low percentage of sand (figure 9).

These results indicate elevations of selected contaminants (PAHs, HCB) in Allen Harbor relative to other areas of mid-Narragansett Bay. However, concentrations at all stations, including Allen Harbor, were generally low compared to other estuarine sediments in the northeast U.S. For instance, total PCBs in Allen Harbor averaged 318 ng/g dry weight (ppb), whereas PCBs in New Bedford Harbor (NBH), a designated Superfund site, range from 149,000 to 585,000 ppb in the top 2 inches (5 cm) of subtidal sediment in the most heavily affected locations (Hansen et al., 1986). Similarly, Munns et al. (1988) found PCB concentrations of 6,490 ppb in Black Rock Harbor (BRH), a small industrialized embayment located near Bridgeport, Connecticut. Gardner and Pruell (1987) reported PCB concentrations of 305 to 1,650 ppb in
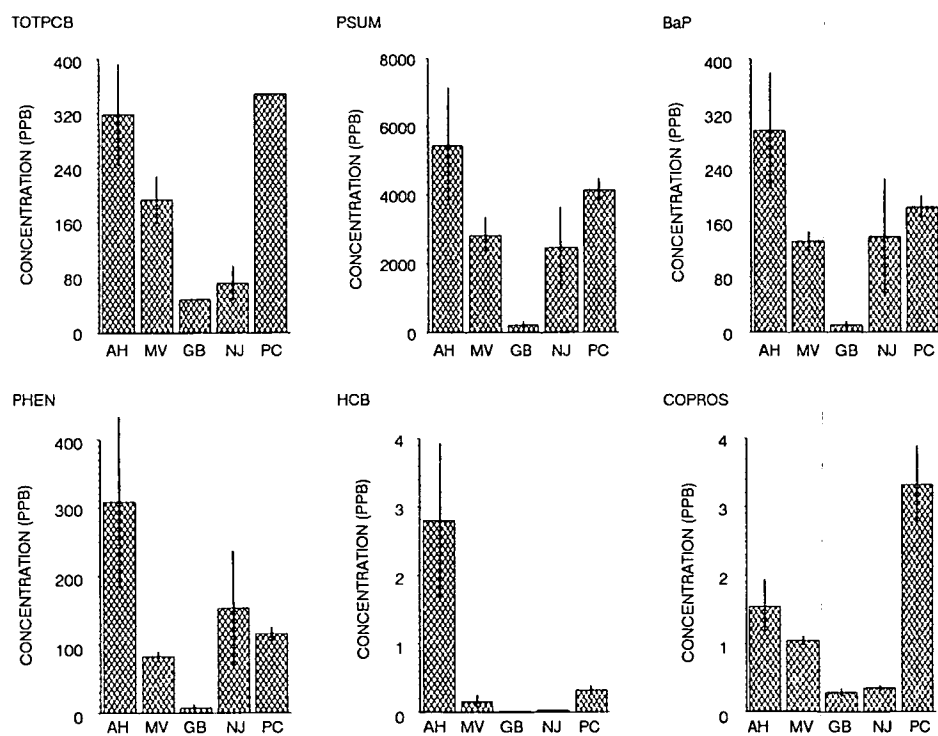
(a) Organic, Narragansett Bay stations.
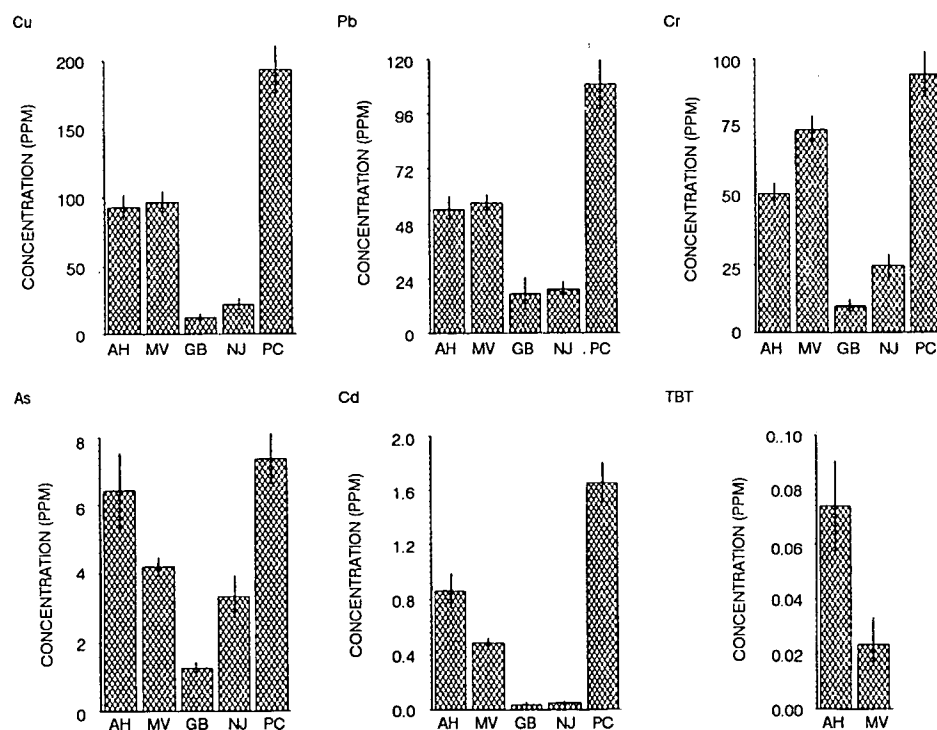
(b) Metal, Narragansett Bay stations.

Figure 11. Levels of selected organic and metal contaminants in subtidal sediments (error bars are standard errors). (Contd)

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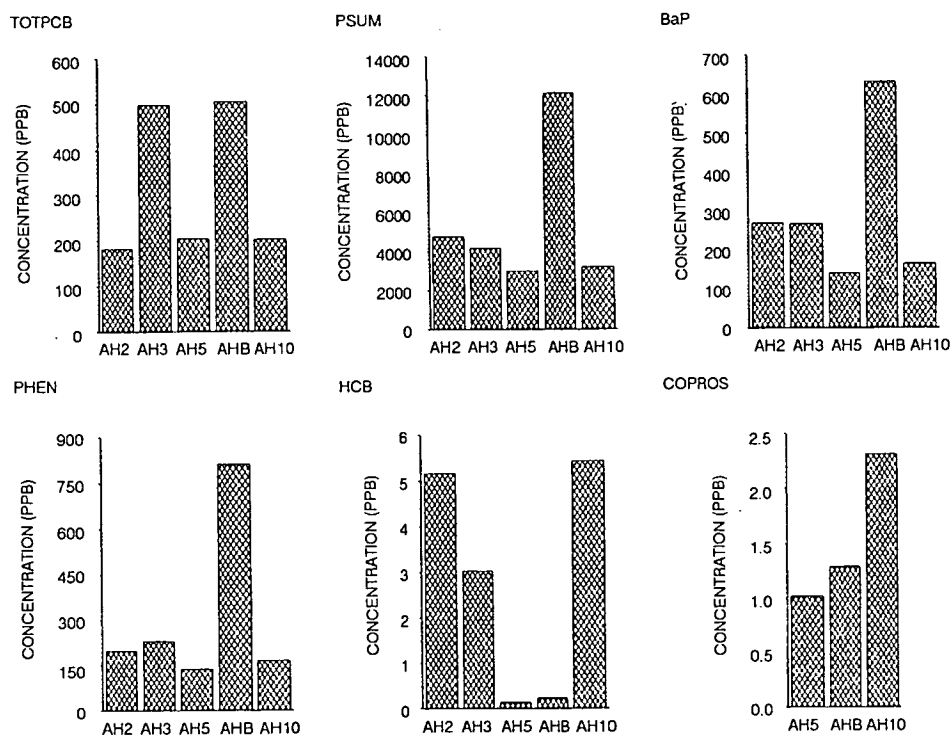
(c) Organic, Allen Harbor stations.
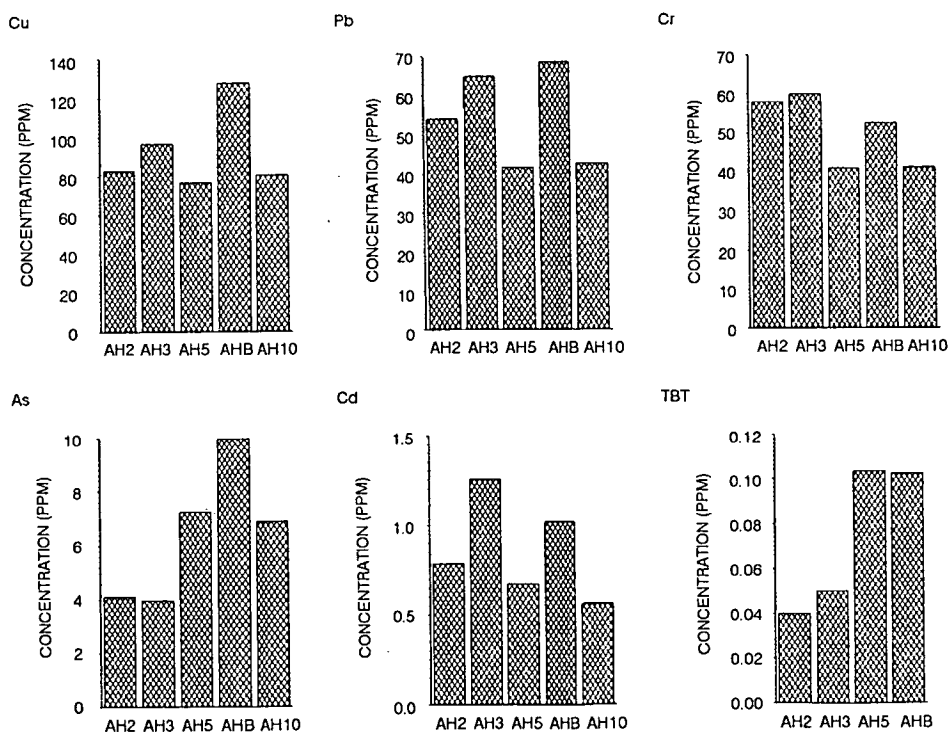
(d) Metal, Allen Harbor stations.

Figure 11.   Continued.

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Table 12. Summary of subtidal sediment ANCOVA, with sand as the covariate.

Contaminant	Station Effect [a]	Sand Effect [a]	Tukey's Comparison[b]
A-BHC	NS	NS	
G-BHC	NS	NS	
A-CHLOR	NS	NS	
G-CHLOR	NS	NS	
DDD	NS	NS	
DDE	NS	NS	
DDT	NS	NS	
HCB	0.001	NS	<u>AH PC MV</u> NJ GB
Cu	0.0001	0.01	<u>PC MV AH</u> NJ GB
Zn	0.0001	0.001	<u>PC AH MV</u> NJ GB
Cr	0.0001	0.0001	<u>PC MV AH</u> NJ GB
Pb	0.0001	0.01	<u>PC MV AH</u> NJ GB
Ni	0.0001	0.01	<u>PC AH MV</u> NJ GB
Cd	0.0001	NS	<u>PC AH MV</u> NJ GB
Mn	0.0001	0.0001	<u>MV PC AH</u> NJ GB
Fe	0.0001	0.0001	<u>AH PC MV</u> NJ GB
Ag	0.0001	0.05	<u>PC</u> MV AH NJ GB
Hg	NS	NS	
As	0.0001	0.05	<u>PC AH MV NJ GB</u>
PHEN	NS	NS	
B(a)P	0.02	NS	<u>AH PC NJ MV</u> GB
PSUM	0.03	NS	<u>AH PC MV NJ</u> GB
A1242	NS	NS	
A1254	NS	NS	
TOTPCB	NS	NS	
COPROS	0.001	NS	PC <u>AH MV NJ GB</u>
CHOLR	0.0001	NS	PC <u>AH MV NJ GB</u>
CHOLN	0.0001	NS	PC AH <u>MV NJ</u> GB
MBT	NS	NS	
DBT	NS	NS	
TBT	NS	NS	

[a] Table entries correspond with the probability that the observed differences in effect level occurred strictly by chance. Low values infer highly significant differences.
NS = not significant.

[b] A mean separation test used when significant station differences were observed. Station designations are ordered from highest mean to lowest mean. Groupings joined by underscoring were not significantly different at P = 0.05.

Quincy Bay (Boston Harbor) sediments. By comparison, reference sediments collected from Central Long Island Sound (CLIS) for laboratory experimentation average 78 ppb. Similar conclusions can be drawn from comparisons involving other contaminants, including PAHs and lead (table 13).

Table 13. Dry-weight concentrations of selected contaminants in Northeastern U.S. subtidal sediments.

Location	Contaminant					
	PCB (ppb)	Cu (ppm)	Cd (ppm)	Pb (ppm)	Total PAH (ppb)	Reference
Allen Harbor, RI	318.2	92.75	0.86	54.38	5,446	This report
New Bedford Harbor, MA	149,000–585,000	143–2,920	1.75–92.6	54.9–888	nm*	Hansen et al. (1986)
Quincy Bay, MA	305–450	45–315	0.40–1.68	43.7–147	3,150–18,400	Gardner and Pruell (1987)
Black Rock Harbor, CT	6,490	2,900	24.7	420	146,400	Munns et al. (1988)
Central Long Island Sound	63.9–97.5	57–69	0.23–0.47	47–57	4,000–5,880	Munns et al. (1988)

*Not measured.

Although there was no difference in butyltin concentrations between the Allen Harbor and Mount View sites (only subtidal sediments were analyzed for butyltin), the concentrations measured are similar to those in other, more heavily used harbors around the U.S. For instance, TBT levels ranged from 10 (at MV) to 100 (in Allen Harbor) ppb dry weight in the current study, whereas levels of 9.1-178 ppb have been reported for San Diego, California (Grovhoug et al., 1986), and of 0-154 ppb in sediments in Pearl Harbor and in other Hawaiian locations (Stang and Seligman, 1987). Although TBT concentrations of up to 17,000 ppb have been encountered (Humphrey and Hope, 1987), most studies report levels of 0-50 ppb in sediments (e.g., Grovhoug et al., 1986; Weber et al., 1986). With this finding in mind, Phase II activities will re-examine the butyltin levels in the harbor.

Within Allen Harbor proper, subtidal sediment from station AH5 at the center of the harbor typically contained lower contaminant concentrations than those elsewhere within the harbor (figure 11). Conversely, station AH8 at the southern end of the harbor usually exhibited the highest levels. Of the 52 contaminants measured in this study, only 8 (15%) exhibited their highest levels near the landfill; 10 compounds (20%) would be expected to be highest at that station based on random chance alone. The 8 included Mn, alpha- and gamma-chlordane, DDD, DDT, anthracene, and the two benzotriazoles. Pesticides were generally quite low in seep and ground water

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(Appendix G) and were not reported to have been deposited in the landfill (table 8). Thus, little evidence of current contaminant migration from the landfill was observed. Similarly, the two stations closest to Calf Pasture Pt. (AH3 and AH10) exhibited no elevations in the contaminants reported deposited at that site.

The broad chemical patterns observed within Allen Harbor are unrelated to grain size distribution (as determined by Spearman rank correlation analyses), although the number of samples involved in these analyses was not sufficient to detect subtle relationships. Activities in Phase II will provide additional information with which to address these patterns.

Intertidal Sediments. Concentrations of representative contaminants in intertidal sediments are presented in figure 12. No differences in contaminant level (as determined by ANCOVA, with percent sand as the covariate) were observed between Allen Harbor and Marsh Point, the only sites receiving replicate analytical effort (table 14). However, there was a large variation in concentration among all stations. For instance, mean Pb and Cu levels were an order of magnitude higher in Allen Harbor than at CC, MP, or FDA (figure 12). Conversely, CC contained B(a)P concentrations nearly 20 times those in Allen Harbor and over 30 times those observed at FDA. Total PAH levels differed in a similar fashion. The causes of this variation are not clear.

Table 14. Summary of intertidal sediment ANCOVA, with sand as the covariate.

Contaminant	Station Effect [a]	Sand Effect [a]
Cu	ns	ns
Zn	ns	ns
Cr	ns	0.01
Pb	ns	ns
Cd	ns	ns
Mn	ns	ns
Fe	ns	0.02
Ag	ns	ns
Hg	ns	ns
As	ns	ns
PHEN	ns	ns
B(a)P	ns	ns
PSUM	ns	ns

[a] Table entries correspond with the probability that the observed differences in effect level occurred strictly by chance. Low values infer highly significant differences. ns = not significant.
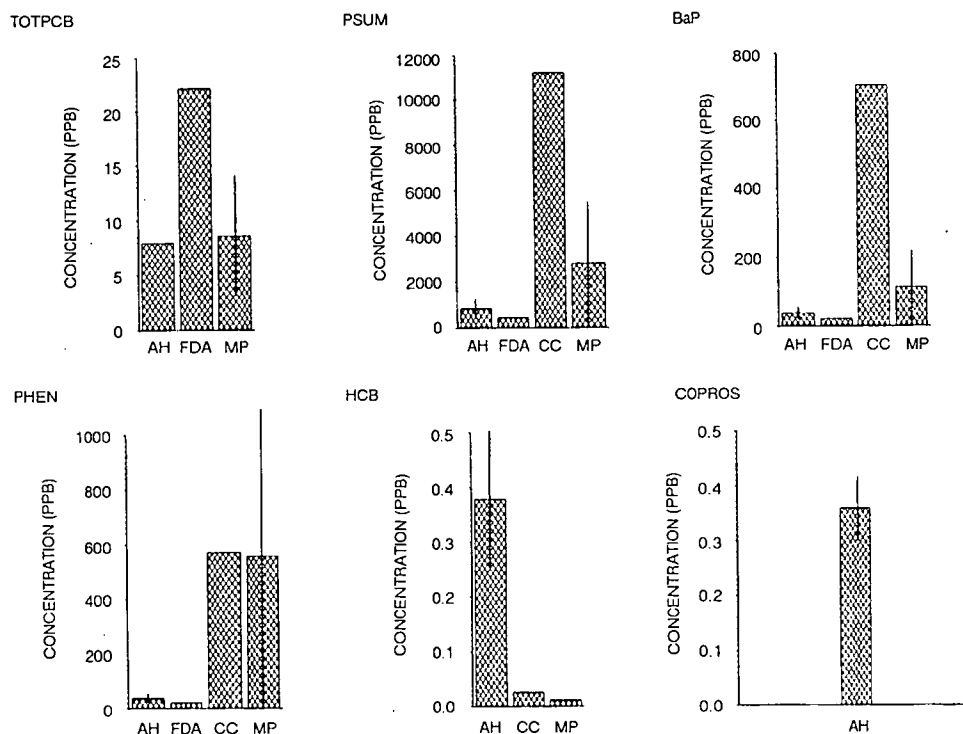
(a) Organic, Narragansett Bay stations.
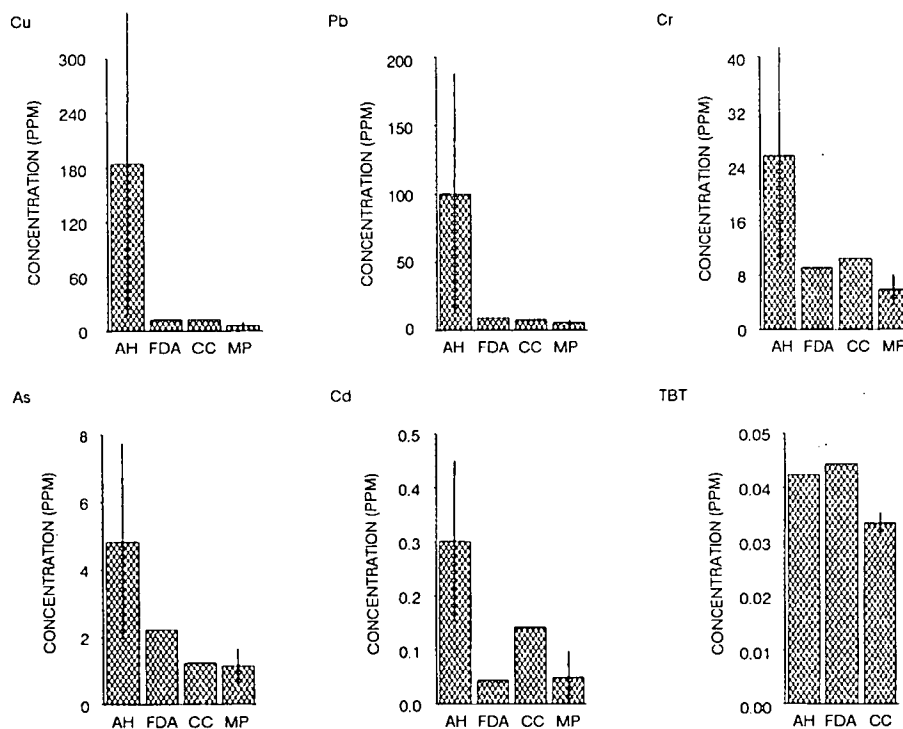
(b) Metal, Narragansett Bay stations.

Figure 12. Levels of selected organic and metal contaminants in intertidal sediments (error bars are standard errors).   (Contd)
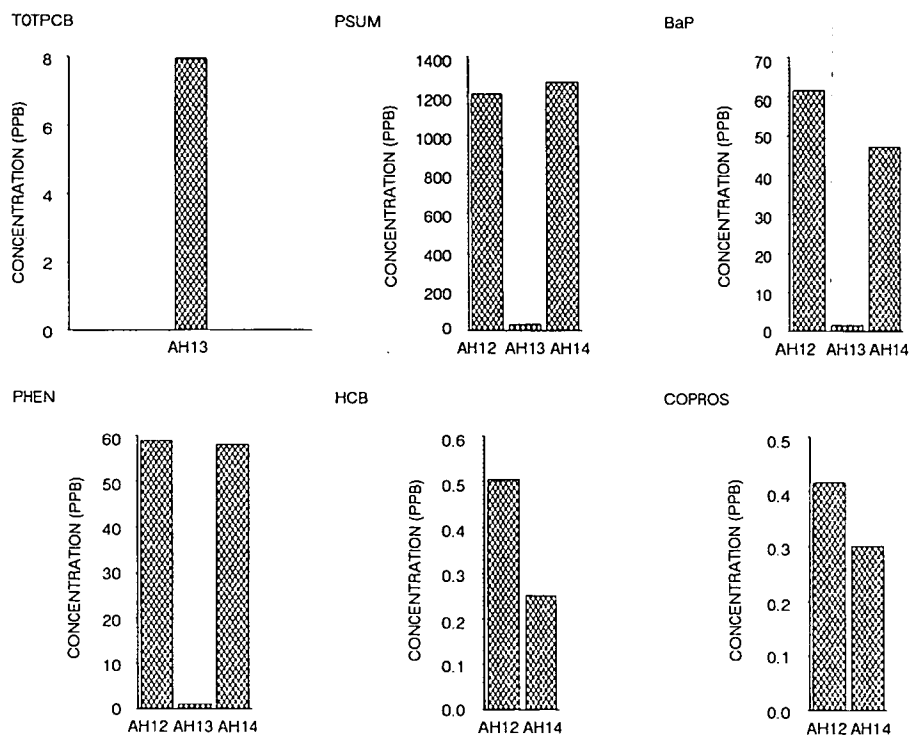
(c) Organic, Allen Harbor stations.
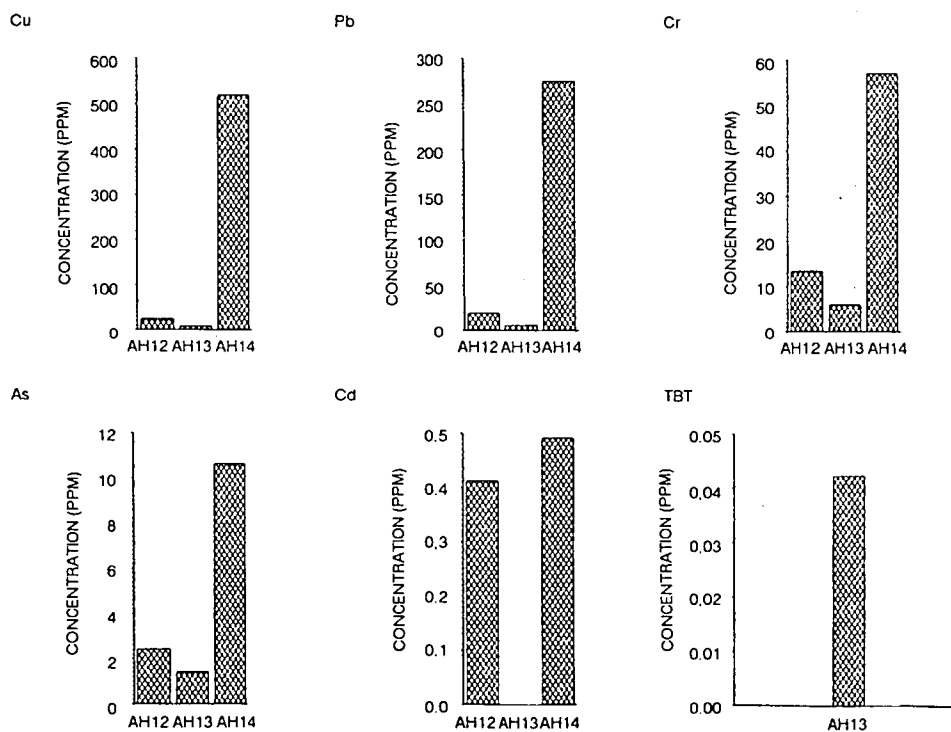
(d) Metal, Allen Harbor stations.

Figure 12. Continued.

Differences were also indicated between intertidal pollutant levels and those seen in subtidal sediments. Intertidal PCB concentrations in Allen Harbor were roughly a factor of 40 lower than their subtidal counterparts. This may reflect losses due to volatilization or aerobic microbial degradation. Mean concentrations of the majority of metals were within a factor of 2 between intertidal and subtidal sediments, with no consistent trends between the two matrices. Sterol and butyltin concentrations were lower intertidally than those seen in the subtidal sediments.

Within Allen Harbor, pollutant levels were typically lowest at the south end of the landfill (AH13). Concentrations at AH12, north of the landfill, and AH14, east of Calf Pasture Pt., were similar except in the case of metals (figure 12). Levels of Cr, As, Pb, and Cu were 4 to 20 times higher at AH14. Because such elevations may reflect contaminant migration into Allen Harbor from waste disposal sites on Calf Pasture Pt., this sample has been targeted for reanalysis to ascertain the validity of the levels encountered.

Tissue Residues

Quahogs. Concentrations of representative contaminants measured in the soft tissues of *Mercenaria mercenaria* are shown in figure 13. Differences observed among stations in mean concentration were often significant (ANOVA, $P<0.05$), although few patterns were discernible with respect to these differences (table 15). Unlike the results obtained for subtidal sediments, no station consistently exhibited the highest levels of contaminants. Allen Harbor often grouped with stations exhibiting the highest mean concentration for particular contaminants (approximately 40% of the time as determined by Tukey's studentized range test), but was significantly elevated above all four other stations for iron only. This metal is unimportant toxicologically at the levels observed here. Allen Harbor quahogs also contained higher ($P \approx 0.01$) TBT levels than those from Mount View, the only other station analyzed (table 15). AH TBT levels were approximately twice those observed in MV animals. It is interesting to note that levels of Cr and As were lowest in AH animals.

PCB and PAH levels measured in this study are comparable to those reported by Pruell et al., (1988b) for quahogs from upper and mid-Narragansett Bay. They observed PCB concentrations in animals from Greenwich Bay and Mount View to be 160 and 238 ppb, respectively, whereas corresponding means from this study are 142 and 158.3 ppb. Throughout the upper and mid-Bay, PCB values ranged from 155 to 358 ppb, with the lowest concentrations measured in Mount Hope Bay and the highest concentrations in the Providence River (Pruell et al., 1988b). A similar distribution was reported for PAHs, which ranged from a low of 147 ppb in Greenwich Bay to a high of 427 ppb in the Providence River (Pruell et al., 1988b). Residues of PAHs measured during this study for quahogs collected from Greenwich Bay and Mount View (167.6 and 317 ppb, respectively) are comparable to PAH residues reported for quahogs
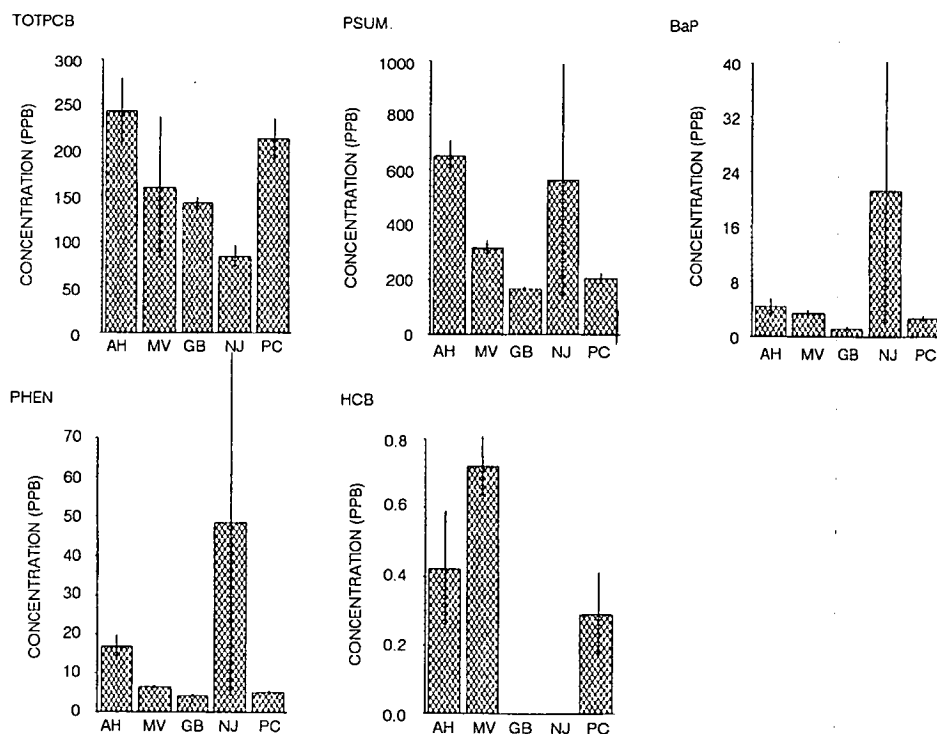
(a) Organic, Narragansett Bay stations.
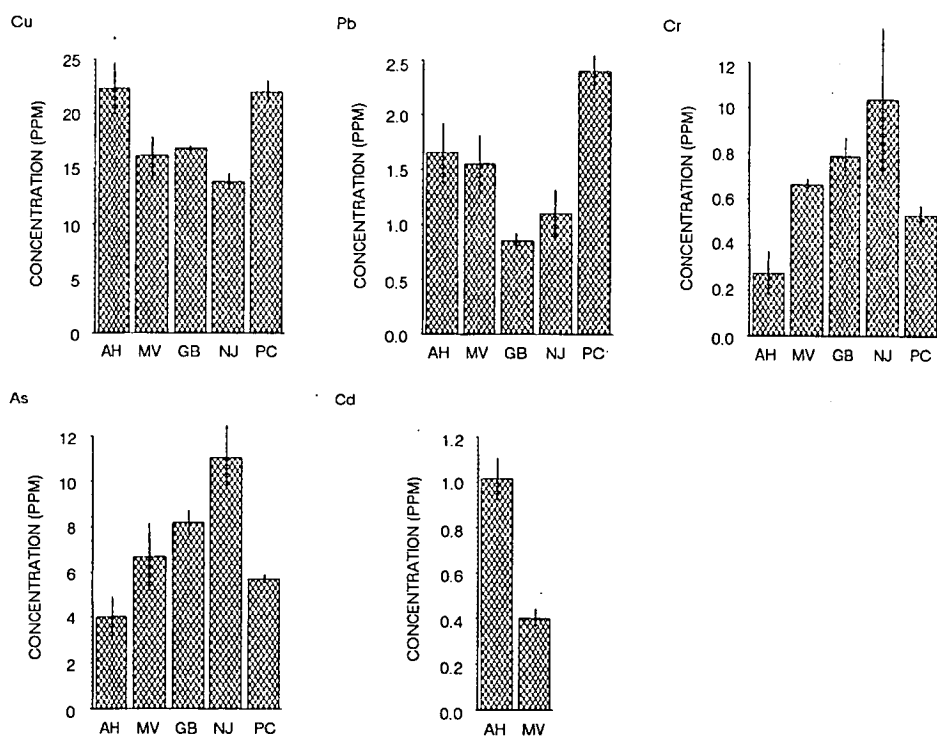
(b) Metal, Narragansett Bay stations.

Figure 13. Levels of selected organic and metal contaminant residues in indigenous *Mercenaria mercernaria* tissue (error bars are standard errors).

(Contd)

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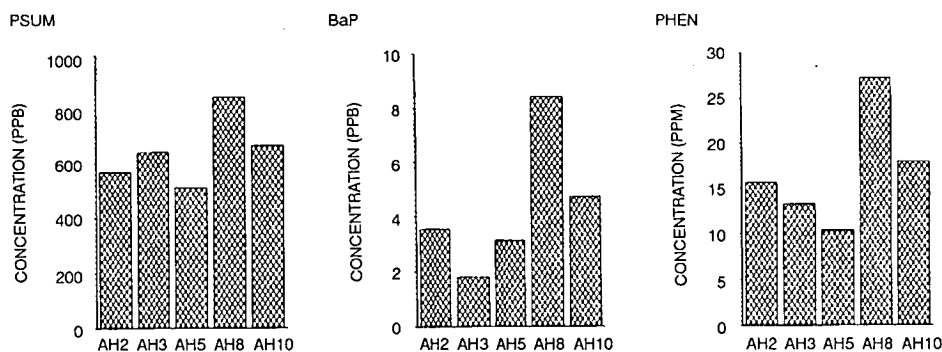
(c) Organic, Allen Harbor stations.
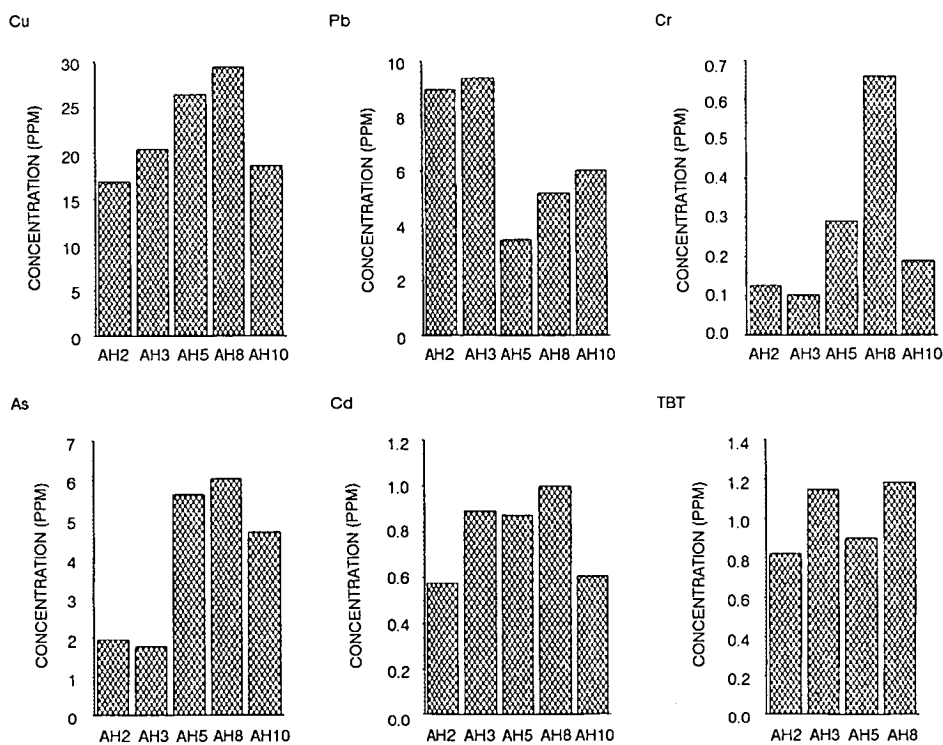
(d) Metal, Allen Harbor stations.

Figure 13. Continued.

Table 15. Summary of *Mercenaria mercenaria* ANOVA.

Contaminant	Station Effect [a]	Tukey's Comparison[b]
A-BHC	0.0035	<u>MV AH PC</u> NJ GB
G-BHC	ns	
A-CHLOR	0.030	
G-CHLOR	0.0004	<u>GB PC MV AH</u> NJ
DDD	ns	
DDE	0.0292	<u>MV AH PC GB</u> NJ
DDT	ns	
HCB	0.010	<u>MV AH PC</u> NJ GB
Cu	0.0014	<u>AH PC GB MV</u> NJ
Zn	ns	
Cr	0.030	<u>NJ GB MV PC</u> AH
Pb	0.0006	<u>PC AH MV</u> NJ GB
Ni	ns	
Cd	0.0057	<u>AH NJ PC GB</u> MV
Mn	0.0219	<u>GB NJ MV AH</u> PC
Fe	0.0001	<u>AH MV NJ PC</u> GB
Ag	0.002	<u>NJ AH PC GB</u> MV
Hg	ns	
As	0.0016	<u>NJ GB MV</u> PC AH
PHEN	ns	
B(a)P	ns	
PSUM	ns	
A1242	ns	
A1254	0.0323	<u>AH PC MV GB</u> NJ
TOTPCB	0.0323	<u>AH PC MV GB</u> NJ
MBT	ns	
DBT	ns	
TBT	0.0112	<u>AH MV</u>

[a] Table entries correspond with the probability that the observed differences in effect level occurred strictly by chance. Low values infer highly significant differences. NS = not significant.

[b] A mean separation test used when significant station differences were observed. Station designations are ordered from highest mean to lowest mean. Groupings joined by underscoring were not significantly different P = 0.05.

previously collected from the Mount View station (279 ppb) (Pruell et al., 1988b). The *M. mercenaria* trace metal concentrations observed in this study (figure 13) are similar to those observed in another infaunal filter feeding bivalve, *Pitar morrhuana* (Eisler et al., 1978), collected from a site just south of Allen Harbor. The levels reported for *P. morrhuana* ranged from 2.3 to 29.6 ppm for copper, 0.7 to 3.3 ppm for cadmium, and 11.1 to 29.4 ppm for lead (Eisler et al., 1978).

Correlations were observed only between a small subset of quahog tissue residues and contaminant concentrations in subtidal sediments (table 16). Copper, lead, and iron were the only compounds to show relationships in concentration (all positive) between the two sample matrices. Because *Mercenaria* is a water-column filter feeder, the small number of significant relationships is not particularly surprising. A stronger dependence of bioaccumulation on sediment chemistry might be expected in deposit-feeding organisms.

Table 16. Significant Pearson correlations between subtidal sediments and *Mercenaria mercenaria* tissue residues.

Contaminant	Correlation Coefficient (r^2)	Probability*
Cu	0.54	0.02
Pb	0.56	0.02
Fe	0.80	0.0001

*Probability of obtaining the observed correlation coefficient by chance.

As with subtidal chemistry levels, tissue residues of quahogs within Allen Harbor were typically highest at station AH8, at the southern end of the harbor (figure 13). Unlike the sediment data, however, residues at AH5 were not particularly low relative to other Allen Harbor stations. Of 49 contaminants measured in quahogs, only 4 (8%) were highest near the landfill at station AH2; 10 would be expected by chance alone. Assuming a soft-tissue wet weight–dry weight ratio of 4:1 (e.g., Connolly, 1991), none of the AH quahog samples violated Hoffman's (1988) proposed alert levels for quahog consumption.

Soft-Shell Clams. Bioaccumulation by *Mya arenaria* provided an additional measure of exposure conditions in Allen Harbor. Levels of representative contaminants measured in *Mya* are illustrated in figure 14. Statistically significant differences between stations were detected for only the pesticides g-BHC, a-chlordane, DBT, and TBT. Although the highest concentrations of g-BHC, DBT, and TBT were measured in Allen Harbor, only the g-BHC data resulted in a statistically separate population of soft-shell clams for Allen Harbor (table 17). Although the results of ANOVA indicated station differences for the two butyltin species, Tukey's procedure failed to separate mean groups.

TOTPCB

PSUM

BaP

PHEN

HCB

(a) Organic, Narragansett Bay stations.

Cu

Pb

Cr

As

Cd

TBT
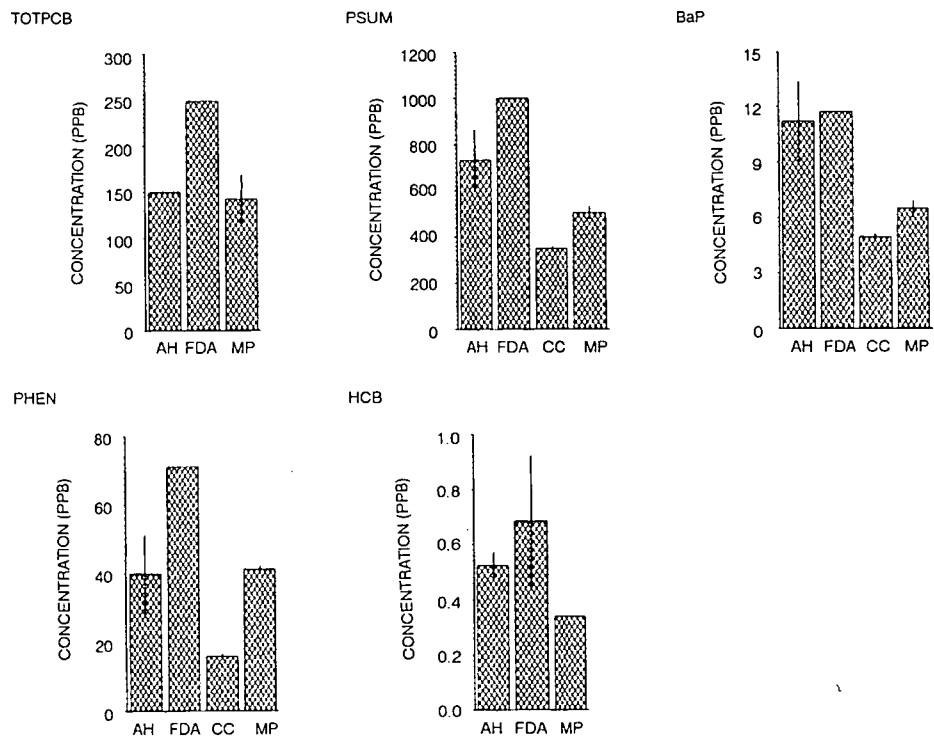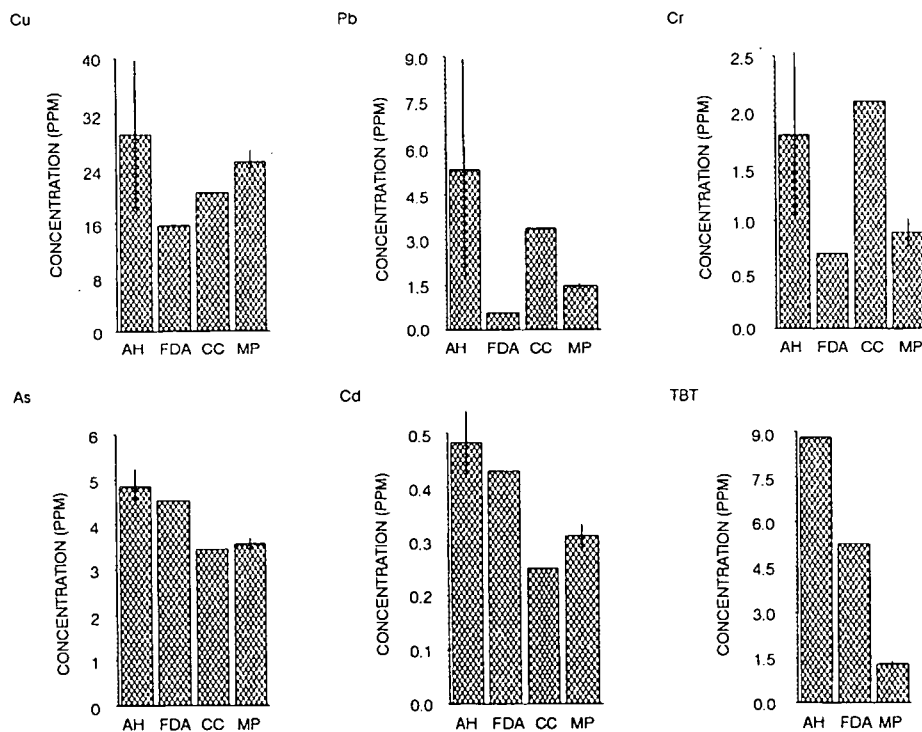
(b) Metal, Narragansett Bay stations.

Figure 14. Levels of selected organic and metal contaminant residues in indigenous *Mya arenaria* tissue (error bars are standard errors).   (Contd)
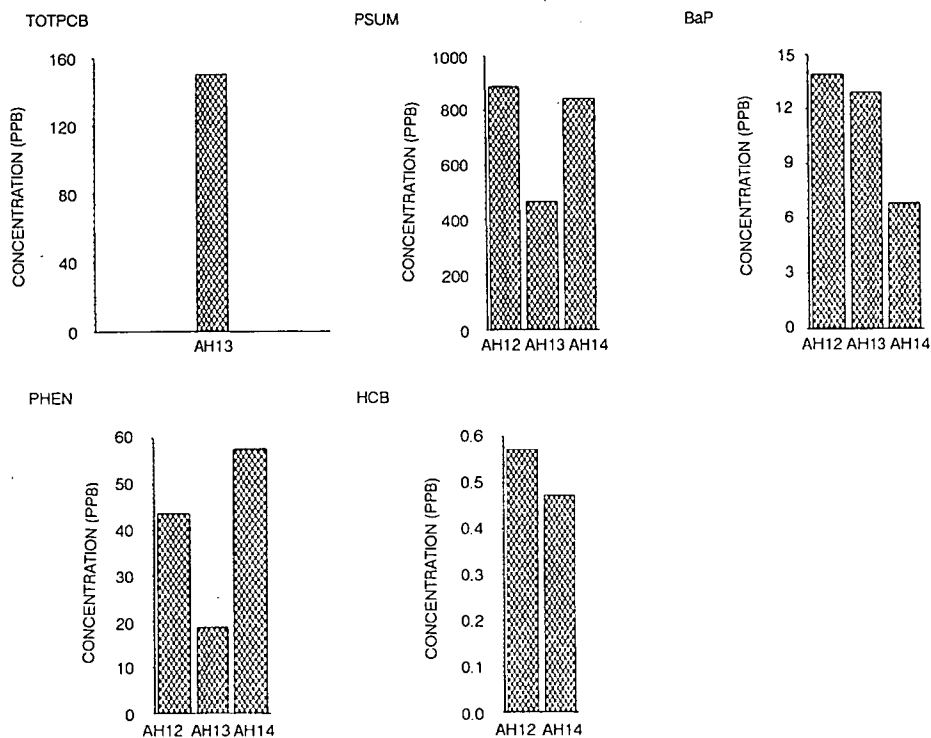
(c) Organic, Allen Harbor stations.
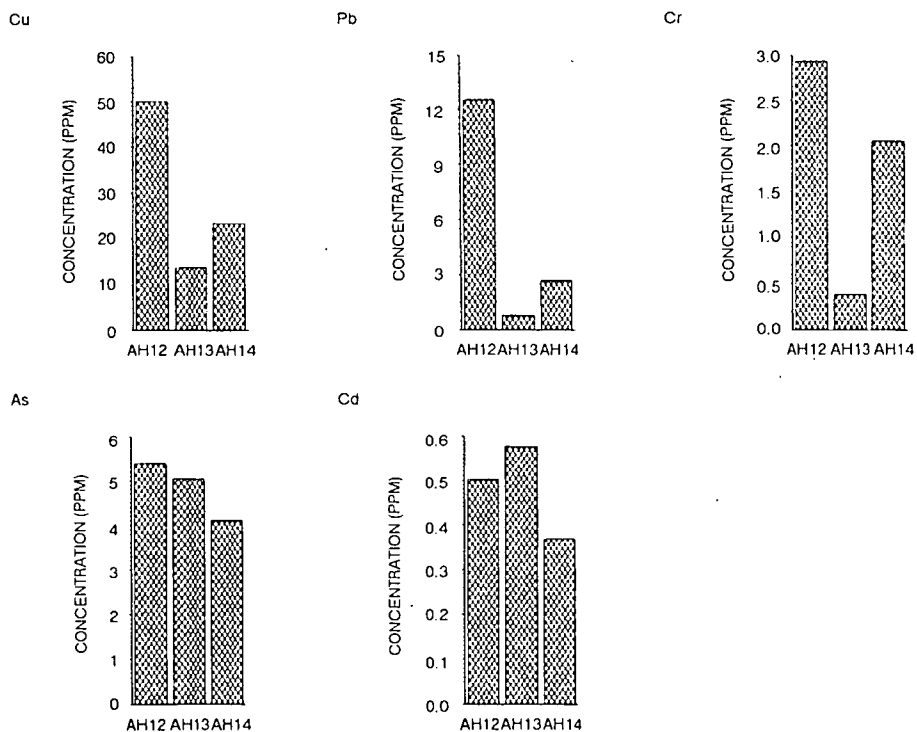
(d) Metal, Allen Harbor stations.

Figure 14. Continued.

Table 17. Summary of *Mya arenaria* ANOVA.

Contaminant	Station Effect [a]	Tukey's Comparison[b]
A-BHC	ns	
G-BHC	0.04	AH MP CC
A-CHLOR	0.05	MP AH CC
G-CHLOR	ns	
DDD	ns	
DDE	ns	
DDT	ns	
HCB	ns	
Cu	ns	
Zn	ns	
Cr	ns	
Pb	ns	
Ni	ns	
Cd	ns	
Mn	ns	
Fe	ns	
Ag	ns	
Hg	ns	
As	ns	
PHEN	ns	
B(a)P	ns	
PSUM	ns	
A1242	ns	
A1254	ns	
TOTPCB	ns	
MBT	ns	
DBT	0.005	AH FDA MP
TBT	0.03	AH FDA MP

[a] Table entries correspond with the probability that the observed differences in effect level occurred strictly by chance. Low values infer highly significant differences. ns = not significant.

[b] A mean separation test used when significant station differences were observed. Station designations are ordered from highest mean to lowest mean. Groupings joined by underscoring were not significantly different at P = 0.05.

Tissue residues of Cu and PAHs in Allen Harbor were somewhat elevated with respect to those in *Mya* from Quincy Bay, Massachusetts, as reported by Gardner and Pruell (1987) (table 18). PCB levels, on the other hand, were several times lower in Allen Harbor animals. Residues of TBT measured in *M. arenaria* were extremely high (8,800 ppb dry weight), 20 times higher than TBT tissue concentrations measured in mussels (425 ppb) collected from TBT-contaminated areas along the East Coast (Wade, Garcia-Romero, and Brooks, 1988). Residues of TBT measured in tissues of quahogs collected from Allen Harbor were 8 times lower than the soft-shell clams for Allen Harbor (figures 12 and 13), reflecting a trend opposite to that seen in intertidal and subtidal sediments. Because TBT degrades fairly rapidly to less toxic DBT and MBT (Seligman et al., 1989), the relative quantities of TBT, DBT, and MBT in soft-shell clam tissues could indicate either a relatively recent exposure to TBT or that the soft-shell clams may preferentially accumulate TBT (see Appendix K, table K-4). Since the hull application of TBT-based antifoulant paint was recently banned, the source of this contaminant is not clear. Phase II activities will assess TBT sources in Allen Harbor in more detail.

Table 18. Dry-weight concentrations of selected contaminants in soft-shell clams.

Location	Contaminant					
	PCB (ppb)	Cu (ppm)	Cd (ppm)	Pb (ppm)	Total PAH (ppb)	Reference
Allen Harbor, RI	150	29.0	0.483	5.34	732	This report
Quincy Bay, MA	997– 1,010	12.3– 14.2	0.12– 1.82	3.08 3.36	281– 299	Gardner and Pruell (1987)

Because of the small sample sizes available to compare tissue residue data with intertidal sediment chemistry, correlation analyses were limited to trace metals and PAHs. No correlations were observed. As with quahogs and subtidal sediment comparisons, the lack of agreement between contaminant levels in these two sample matrices is not surprising.

Contaminant residues were generally higher at AH12 than at other stations within Allen Harbor (figure 14). Of the 43 compounds quantified in soft-shell clams, 20 (47%) exhibited highest levels at this station. These consisted primarily of trace metals and PAHs, differing somewhat from the pattern seen in intertidal sediments. Samples collected for AH14 did not show the disproportionately high levels of metals observed in the intertidal sediment. Residues were again generally lowest in clams from AH13.

Polychaetes. Residue analyses of indigenous *Nephtys incisa* were restricted to ICP trace metals due to the lack of sufficient quantities of polychaete tissue (figure 15). Observed levels of Cu, Zn, Cr, and Fe were statistically indistinguishable between worms collected at Allen Harbor and Mount View. Worms collected from Mount View

had significantly higher concentrations of Pb, Ni, Cd, and Mn residues than worms col-
lected from Allen Harbor (see Appendix F, table F-7).

With the exception of chromium and lead, residues in Allen Harbor polychaetes
were similar to those observed by Munns et al. (1988) in CLIS reference site *Nephtys*.
They reported levels of 21.0–38.6 ppm for Cu, 0.467–1.32 ppm for Cd, 1.33–3.44 ppm
for Pb, 1.63–2.08 ppm for Cr, and 609–1210 ppm for Fe. Chromium concentrations
were substantially lower in AH, whereas lead residues were an order of magnitude
greater in Allen Harbor worms. Interestingly, MV polychaetes contained Pb levels even
greater than those from the harbor.
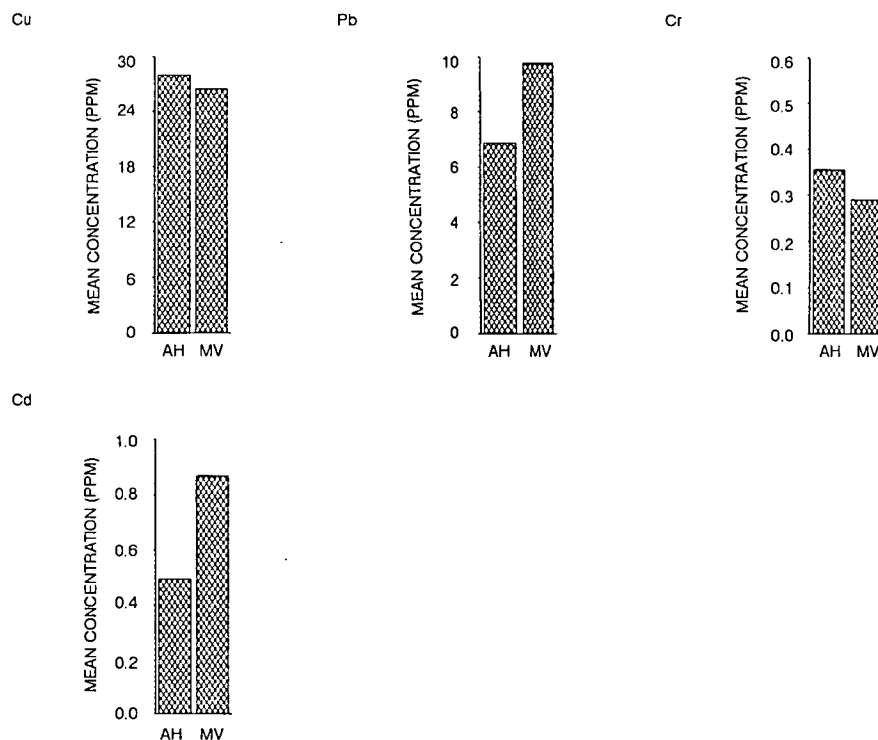
Figure 15. Levels of selected metal contaminant residues
in indigenous *Nephtys incisa* tissue.

Water-Column Exposure

Chemistry. The large-volume water samples from Allen Harbor and Mount View
were analyzed for organic compounds, as described previously. Due to the large size
of sample collected (in excess of 30 liters), the limits of detection could be lowered to

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0.001 ppb or 1 pptr (parts per trillion) for PCBs, and in the sub-pptr range for other organics. Even at this level of resolution, the concentrations of pesticides in both dissolved and particulate phases were generally below detection (Appendix G). PCBs were observed in the particulate phase at concentrations in the 1–2 pptr range, with somewhat higher levels in Allen Harbor. No PCBs were detected in the dissolved phase at either station.

Contaminant levels measured in these samples were similar to background levels observed by Munns et al. (1988) and others in relatively clean areas. In comparison, water column samples collected from NBH contained total PCBs in the 1 μg/L range (Nelson, 1989), three orders of magnitude greater than those seen in the present study.

Whole water samples were also collected in Allen Harbor and at MV for VOC analysis. In general, these samples contained only trace levels of a few compounds (Appendix L). Very low levels of toluene were detected at MV, but not in AH. Acetone was present in all samples.

Tissue Residues

Deployed Mytilus edulis. Concentrations of selected contaminants measured in deployed *Mytilus edulis* are represented in figure 16. Significant differences were found among stations for seven analytes: HCB, Cu, Cd, Ag, total PAHs, MBT, and TBT (table 19). For six of those seven contaminants, the residues of mussels deployed in Allen Harbor fell within the group of stations exhibiting the highest means (as determined by Tukey's studentized range test), but never exhibited the statistically highest level (table 19). Contaminants quantified at TTN, the transect station located outside the mouth to Allen Harbor (figure 16), were typically indistinguishable statistically from those of Allen Harbor animals. Residues in LAB mussels were generally lowest among stations.

Residues quantified in Allen Harbor tissues were fairly typical of clean areas in the Northeast, although PCB and total PAH concentrations were somewhat higher than those reported for other areas (tables 20 and 21). For instance, levels of Cu, Cd, and Pb fell within or below the ranges observed in Lower Narragansett Bay and Central Long Island Sound (Munns et al., 1988), but PCB residues were higher than seen in Lower Narragansett Bay (Pruell et al., 1988b), Block Island Sound (Farrington et al., 1982), and Central Long Island Sound (Munns et al., 1988). Despite these elevations, residue levels were generally lower than those observed in mussels exposed in contaminated areas (tables 20 and 21).
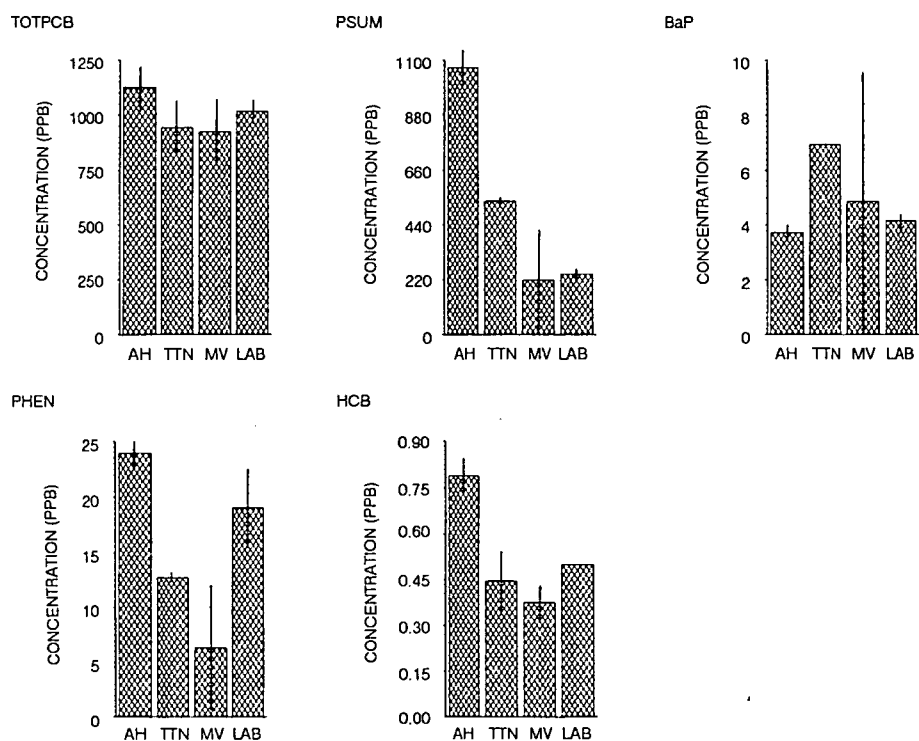
(a) Organic.
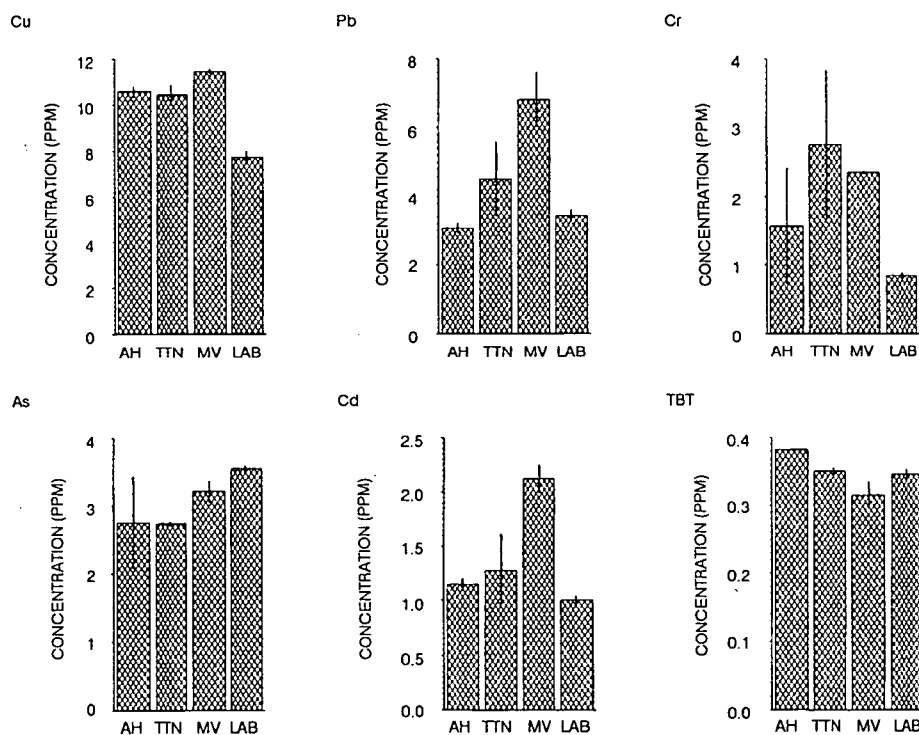
(b) Metal.

Figure 16. Levels of selected organic and metal contaminant residues in deployed *Mytilus edulus* tissue (error bars are standard errors).

Table 19. Summary of *Mytilus eduilis* ANOVA.

Contaminant	Station Effect [a]	Tukey's Comparison[b]
A-BHC	ns	
G-BHC	ns	
A-CHLOR	ns	
G-CHLOR	ns	
DDD	0.056	AH MV TTN LAB
DDE	ns	
DDT	ns	
HCB	0.04	AH LAB TTN MV
Cu	0.003	MV AH TTN LAB
Zn	ns	
Cr	ns	
Pb	ns	
Ni	ns	
Cd	0.04	MV TTN AH LAB
Mn	ns	
Fe	0.05	
Ag	0.005	MV AH LAB TTN
Hg	ns	
As	ns	
PHEN	ns	
B(a)P	ns	
PSUM	0.02	AH TTN LAB MV
A1242	0.03	AH LAB TTN MV
A1254	ns	
TOTPCB	ns	
MBT	0.01	MV AH LAB TTN
DBT	ns	
TBT	0.05	AH TTN LAB MV

[a] Table entries correspond with the probability that the observed differences in effect level occurred strictly by chance. Low values infer highly significant differences. ns = not significant.

[b] A mean separation test used when significant station differences were observed. Station designations are ordered from highest mean to lowest mean. Groupings joined by underscoring were not significantly different $P = 0.05$.

Table 20. Dry-weight concentrations of selected contaminants in deployed blue mussels.

Location	Contaminant				
	Cu (ppm)	Cd (ppm)	Pb (ppm)	Total PAH (ppb)	Reference
Allen Harbor, RI	10.6	1.15	3.07	1,068	This study
Lower Narragansett Bay, RI	5.7–21.8	1.0–3.0	1.1–7.6	200–500	Munns et al. (1988)
New Bedford Harbor, MA	4.3–22.8	0.52–1.47	0.36–11.0	nm*	Boothman, Osterman, and Nelson (1989)
Central Long Island Sound Disposal Site	1,250	15	260	62,500 71,100	Munns et al. (1988)
Central Long Island Sound Reference Site	47–63	0.08–0.24	44–55	2,000–5,806	Munns et al. (1988)

* Not measured.

Table 21. Dry-weight concentrations of total polychlorinated biphenyl (PCB) in blue mussels deployed for 28 days.

Location	PCB (ppb)	Reference
Allen Harbor, RI	1,125	This study
Lower Narragansett Bay, RI	375–402	Pruell et al. (1988a)
New Bedford Harbor, MA	715–97,100	Pruell et al. (1988a)
Coastal Massachusetts	22–366	Farrington et al. (1982)
Block Island and Sakonnet River, RI	102–117	Farrington et al. (1982)
Boston Harbor, MA	635–735	Farrington et al. (1982)
Long Island Sound and South Shore of Long Island, NY	133–838	Farrington et al. (1982)
Central Long Island Sound Sound Reference Site	278–626	Munns et al. (1988)
Central Long Island Sound Dredged Material Disposal Site	700–1,440	Munns et al. (1988)

Butyltin levels in Allen Harbor mussels are in agreement with those observed throughout the east coast. Uhler et al. (1989) reported TBT levels which ranged from 105-798 ppb, DBT levels of 37-402 ppb, and MBT levels up to 46 ppb. Wade et al. (1988) reported levels of 100-160, 70-90, and <5-90 ppb for TBT, DBT, and MBT, respectively, in Long Island Sound animals. Averages for mussels from both coasts are reported by Wade et al. (1988) to be 425, 239, and 221 ppb for TBT, DBT, and MBT, respectively. The butyltin residues measured in the current study are similar to these "average" mussel residues, with the exception of DBT. These DBT residues were roughly 3-4 times the reported average. When compared to the reported levels of butyltins from mussels in nearby areas however, residues of all three tin species are elevated in the present study by factors of 2-20 or more.

Oysters. Tissue residues measured in *Crassostrea virginica* collected from Allen Harbor and Prudence Island (PI) are given in figure 17. Ten contaminants exhibited statistically significant differences between the two stations, including total PCB, total PAHs, and several pesticides (table 22). Allen Harbor residues were higher in all 10 cases.

The residues measured in Allen Harbor were also elevated with respect to those quantified in oysters in other areas of the northeast coast. This is particularly true of PCB, copper, and cadmium. For instance, Farrington et al. (1982) report East Coast oyster PCB residues of 20-336 ppb, and Gardner and Pruell (1987) observed levels of 300-500 ppb in animals deployed in Quincy Bay. Copper and cadmium residues in the latter study were 7.5-40 and 0.27-1.05 ppm, respectively. Lead and PAH levels in the harbor were comparable to those reported by Gardner and Pruell (1987) and Farrington et al. (1982).

A plausible explanation for the elevated tissue residues in the current study may be one involving seasonality. The oysters analyzed during Phase I were collected in December, whereas the Quincy Bay study occurred in July. Munns et al. (1988) found tissue residues in mussels to vary several fold, with highest levels observed in winter. These changes may be related to reproductive and spawning activity, metabolic activity, or differences in the bioavailability of contaminants. Seasonal sampling of oysters in Allen Harbor might lead to a more clear understanding of tissue residue variation.

No patterns in oyster tissue residues were observed across the face of the landfill.
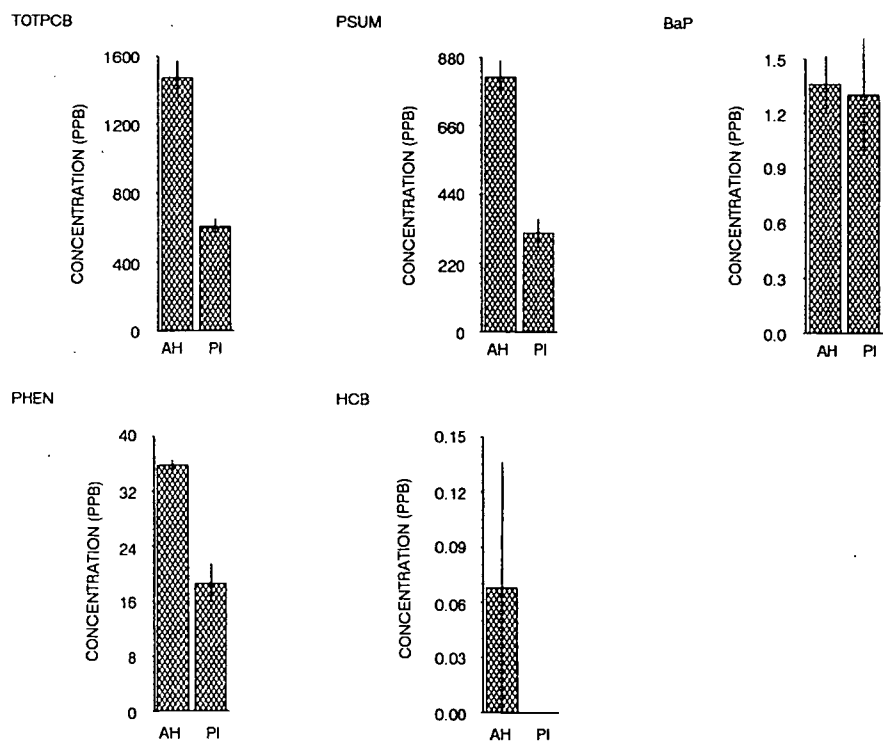
(a) Organic.
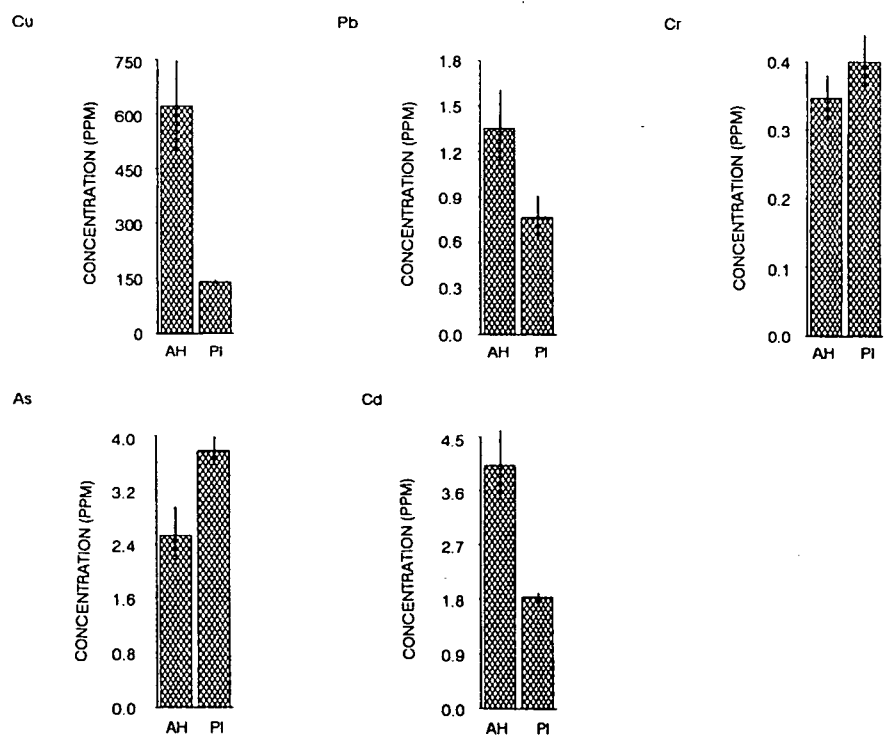
(b) Metal.

Figure 17. Levels of selected organic and metal contaminant residues in indigenous *Crassostrea virginica* (error bars are standard errors).

Table 22. Summary of *Crassostrea* ANOVA.

Contaminant	Station Effect [a]	Tukey's Comparison[b]	
A-BHC	ns		
G-BHC	ns		
A-CHLOR	0.004	AH	PI
G-CHLOR	0.008	AH	PI
DDD	ns		
DDE	ns		
DDT	0.002	AH	PI
HCB	ns		
Cu	0.02	AH	PI
Zn	ns		
Cr	ns		
Pb	ns		
Ni	ns		
Cd	0.02	AH	PI
Mn	ns		
Fe	0.007	AH	PI
Ag	ns		
Hg	ns		
As	ns		
PHEN	0.005	AH	PI
B(a)P	ns		
PSUM	0.002	AH	PI
A1242	ns		
A1254	0.002	AH	PI
TOTPCB	0.002	AH	PI

[a] Table entries correspond with the probability that the observed differences in effect level occurred strictly by chance. Low values infer highly significant differences. ns = not significant.

[b] A mean separation test used when significant station differences were observed. Station designations are ordered from highest mean to lowest mean. Groupings joined by underscoring were not significantly different at $P = 0.05$.

EFFECTS ASSESSMENT

Status of Indigenous Organisms

Population Density, Structure, and Condition. Abundance, population size, population structure, and general condition of indigenous bivalves were characterized during the first quarterly sampling in the winter of 1988. Subsequent samplings in the spring, summer, and autumn provided information regarding size and condition only.

Quahogs. *Mercenaria* in Allen Harbor were significantly smaller than those found at all stations but PC (figure 18). Despite the closure of Allen Harbor to shell fishing in 1984, mean shell length was 2-3 cm shorter than that of animals collected from Mount View, Greenwich Bay, and North Jamestown. This situation was observed during all four sampling periods. Reduced shell size may reflect some impact of sediment or water quality, or may simply be the result of a lack of sufficient time for substantial individual growth following the heavy fishing pressure realized by Allen Harbor quahogs before harbor closure. No data are available to relate current fishing pressure at the bay stations with that experienced in Allen Harbor before 1984.

Condition index, a measure of animal health, followed a pattern among stations similar to that of shell length (figure 19). In every collection, quahogs in the harbor exhibited significantly lower ratios of soft-tissue weight to shell size. As with shell length, the causes of this reduction are unclear. Food availability or quality, sediment characteristics, and temperature (Nelson et al., 1987) are all known to affect the relationship between soft tissue and shell growth. Although not supported by the chemistry results reported earlier, sediment and water column contamination also may play some role.

Proximity to the landfill had no discernible effect on *Mercenaria* length or condition (figure 20). Samples collected nearest the landfill (AH1 and AH2) contained among the highest means of all AH stations. Perhaps reflecting aspects of sediment chemistry, quahog shell length was lowest and condition index second lowest at station AH8 at the south end of the harbor.

Soft-Shell Clams. Densities of *Mya* were higher at Allen Harbor than at Marsh Point or Coggeshall Cove in December 1989 (figure 21). This pattern most likely reflects the intensity of recreational clamming in each area. MP is an extremely heavily fished mud flat. The intertidal sediment surface is pockmarked with recently dug holes (personal observation). Coggeshall Cove, being accessible primarily only by boat, receives much less attention, whereas the shellfish closure obviously limits harvest in the harbor. The unequal fishing pressure at these stations confounds the assessment of land-based waste site effects on *Mya* abundance. Although the limited number of replicate samples collected at stations within Allen Harbor precludes a detailed analysis, densities were highest at AH13 (figure 22).

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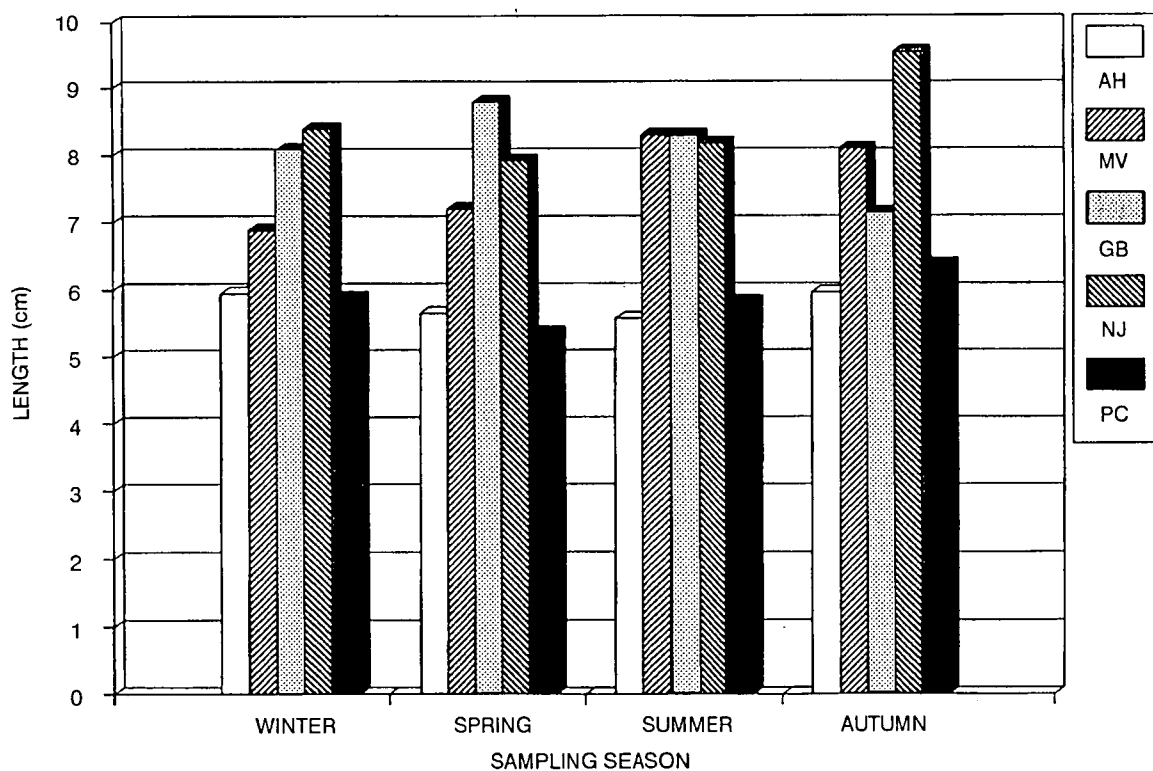
Figure 18. *Mercenaria* shell length at Narragansett Bay stations.
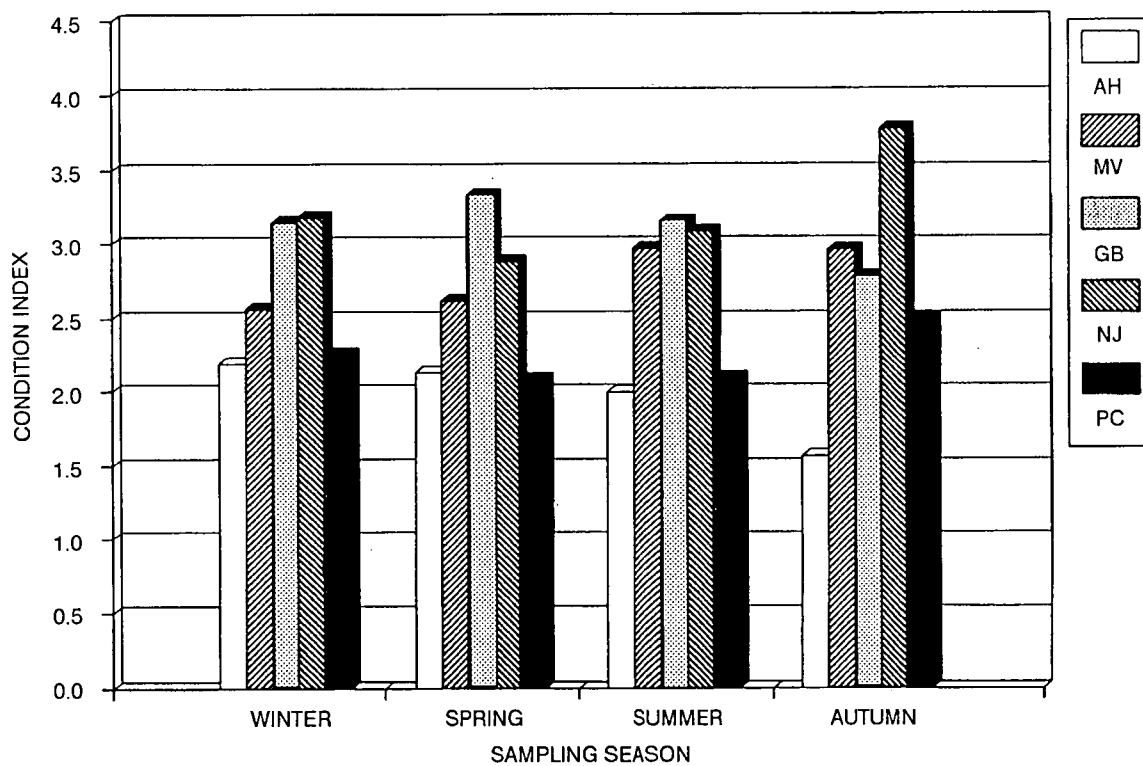
Figure 19. *Mercenaria* condition index at Narragansett Bay stations.
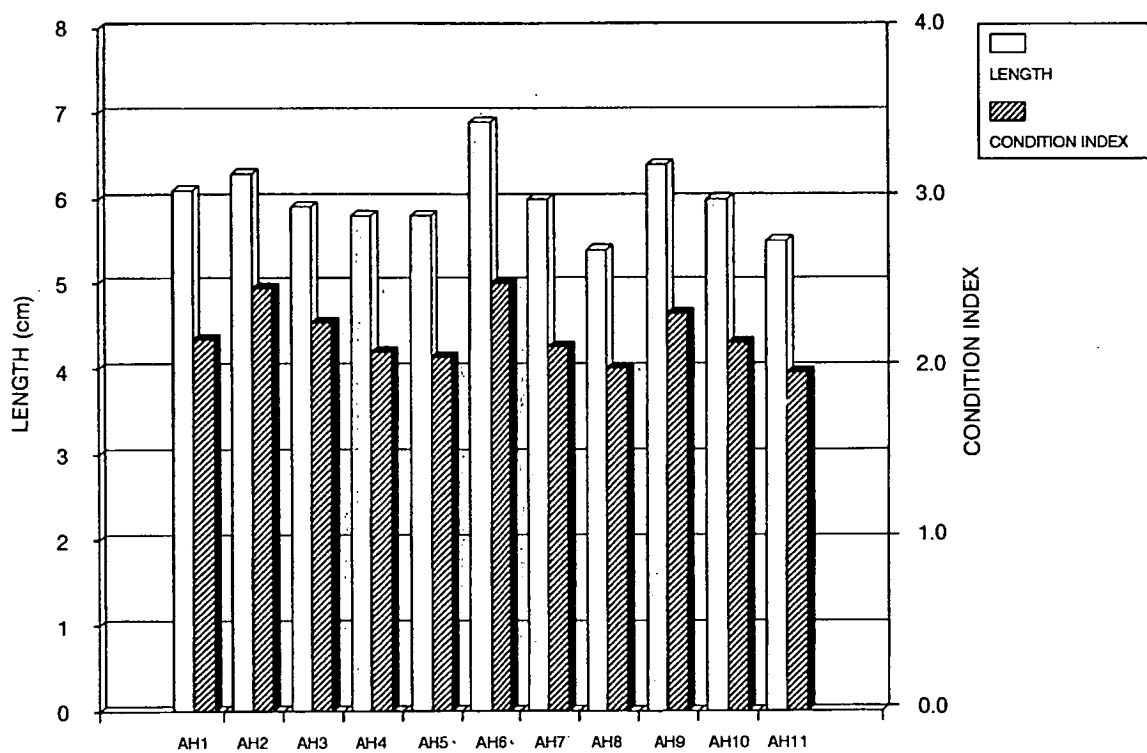
Figure 20. *Mercenaria* shell length and condition index at Allen Harbor stations.
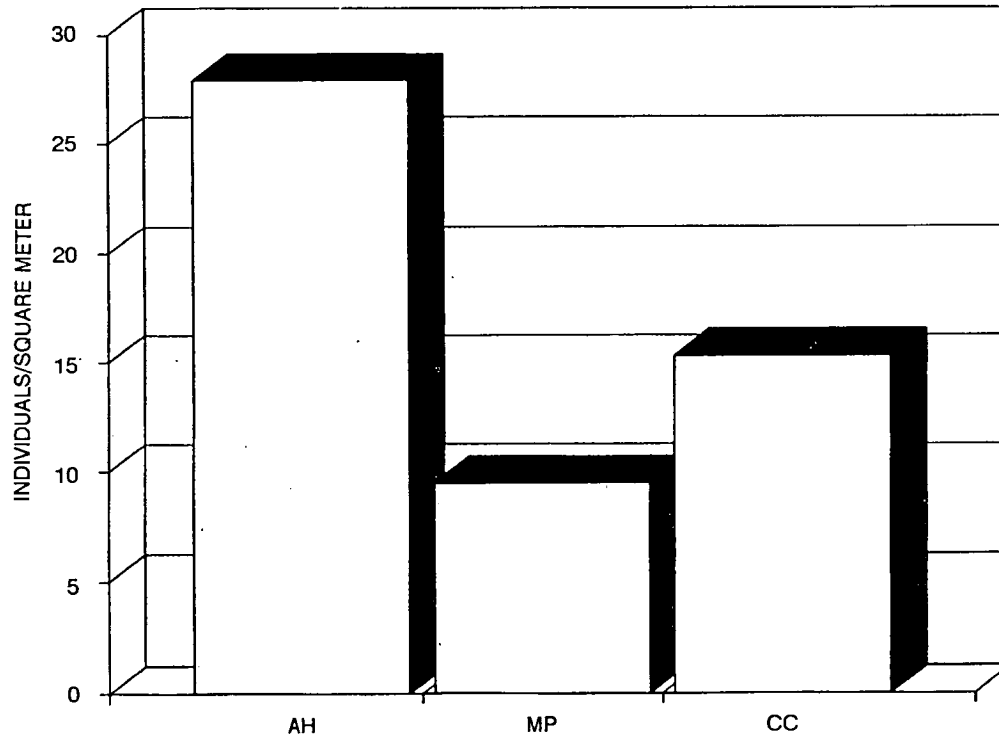
Figure 21. *Mya* densities at Narragansett Bay stations.
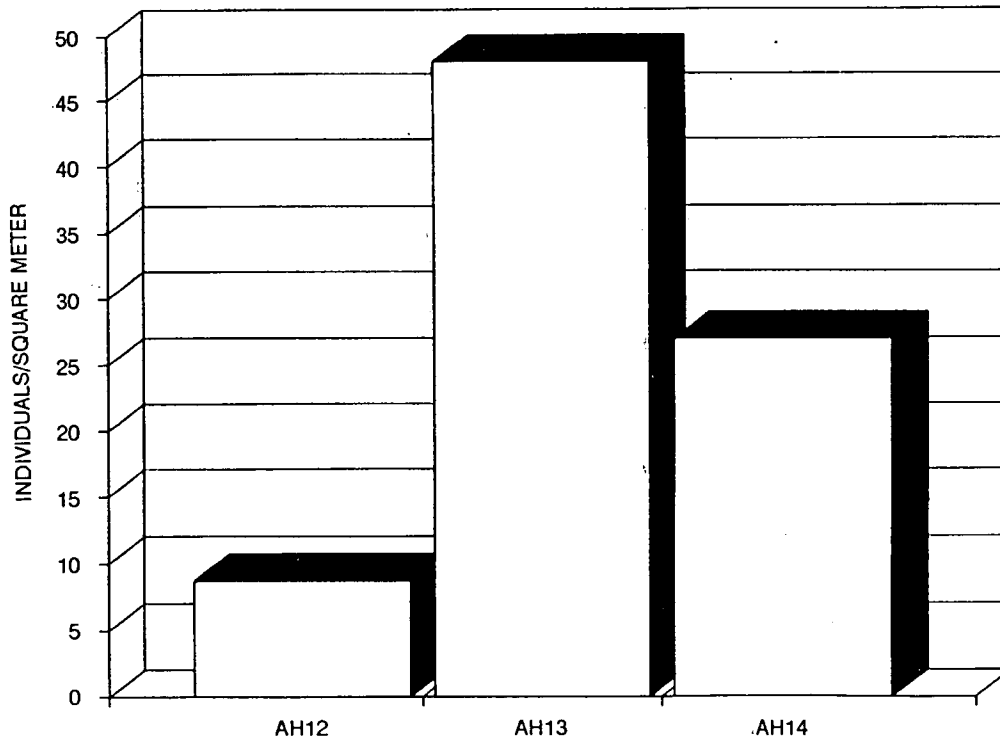
Figure 22. *Mya* densities at Allen Harbor stations.

Unlike the patterns exhibited by quahogs, no clear pattern in *Mya* shell length emerged in station-wise comparisons, although Allen Harbor animals were typically larger than those from Marsh Point and Coggeshall Cove (figure 23). Fishing intensity is again a likely explanation of this result. No discernible trends were evident across stations within the harbor (figure 24).

Relationships among stations in soft-shell clam condition index also varied across seasons (figure 25). Allen Harbor clams on average were more robust than those from other sites in autumn, but were the least robust in spring. Overall, no station differences were apparent.

As with quahogs, proximity to the landfill had little apparent effect on Allen Harbor *Mya* shell length (figure 24) or condition (figure 26). Samples were not collected at AH13 during the summer sampling period.

Oysters. Crassostrea in Allen Harbor were both larger (figure 27) and in better condition (figure 28) than those at PI. Shell fishing pressure may explain these differences.
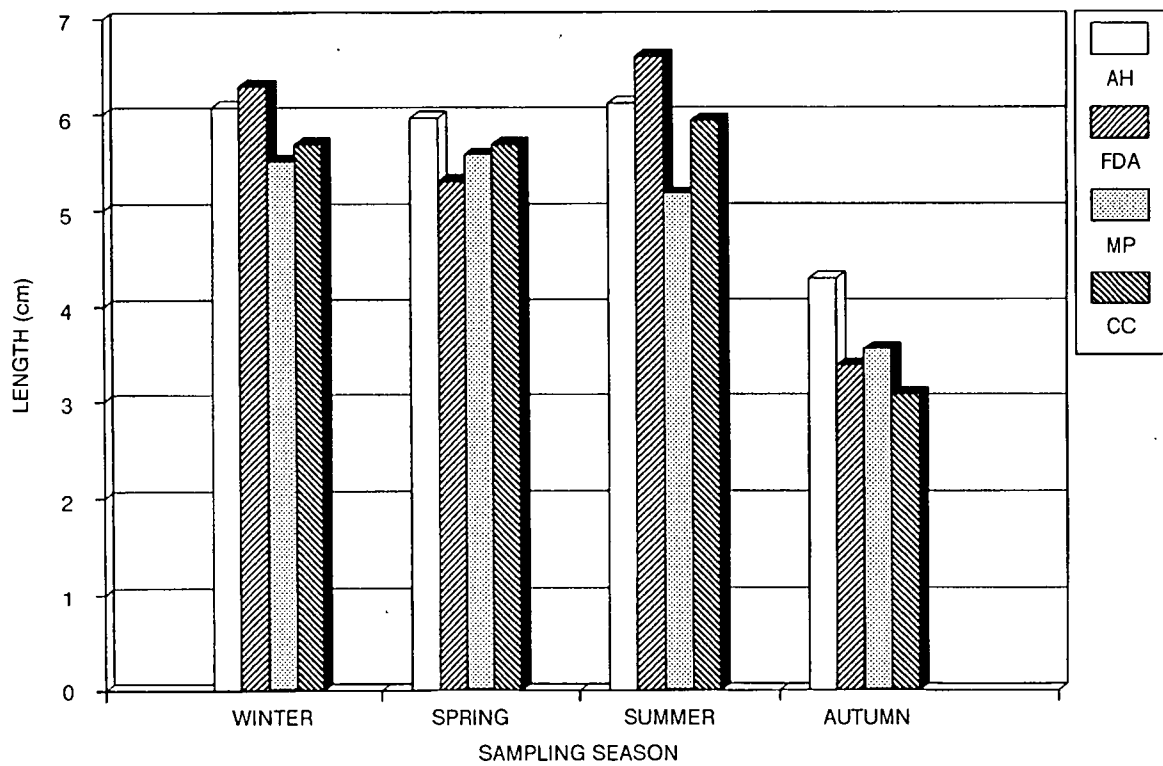
Figure 23. *Mya* shell length at Narragansett Bay stations.
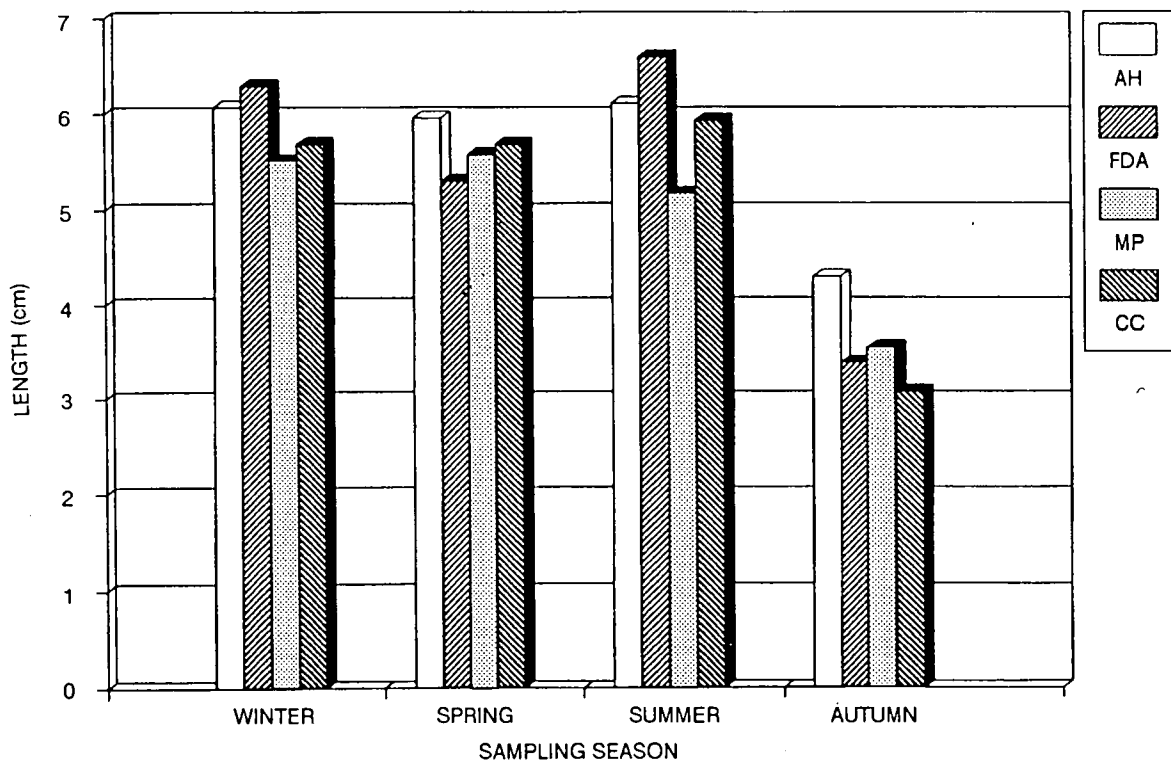
Figure 24. *Mya* shell length at Allen Harbor stations.
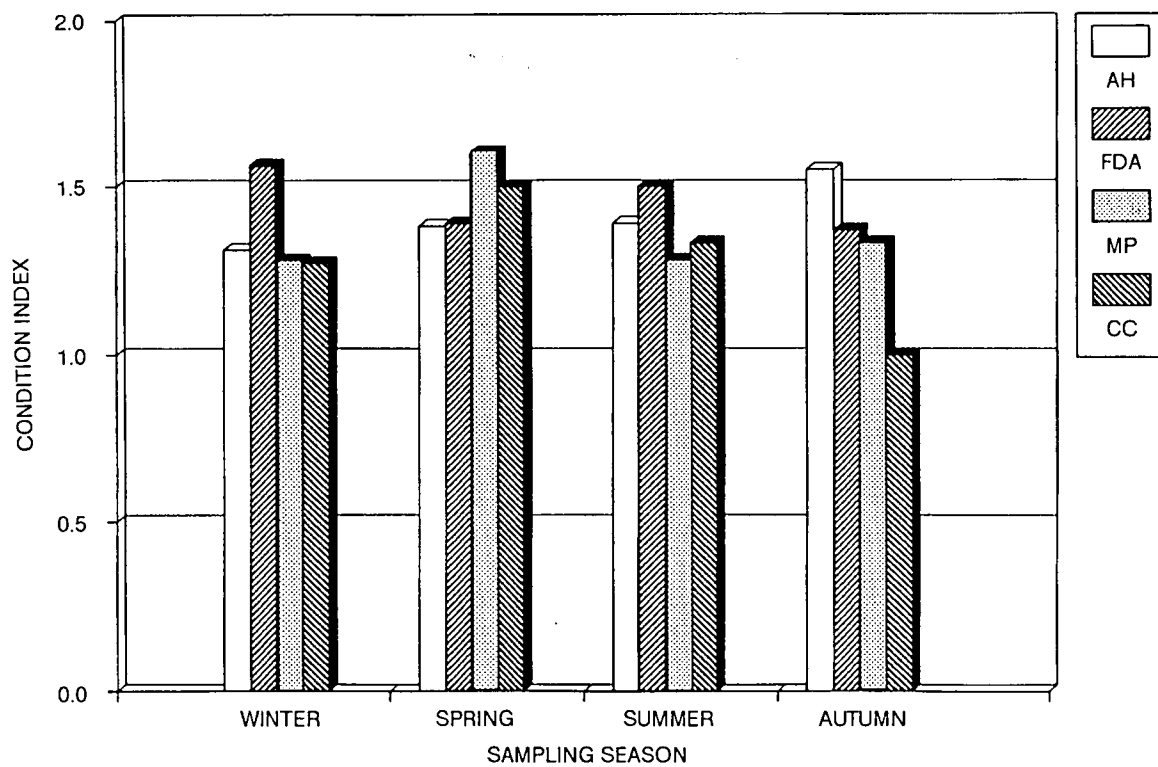
Figure 25. *Mya* condition index at Narragansett Bay stations.
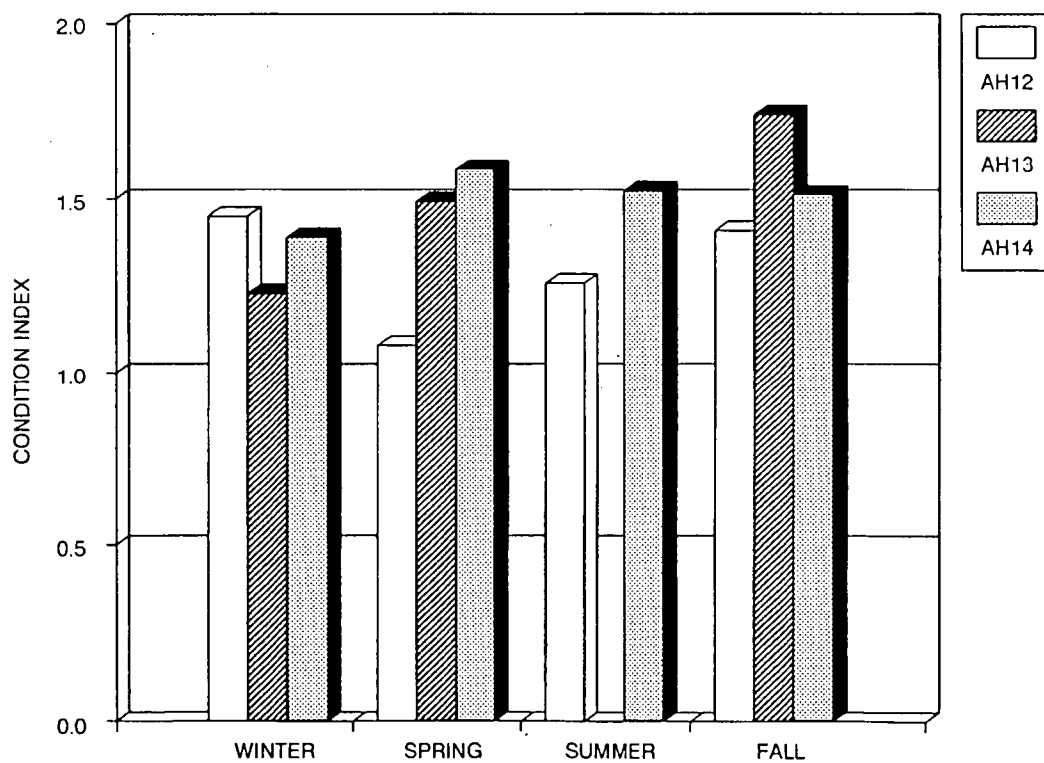
Figure 26. *Mya* condition index at Allen Harbor stations.

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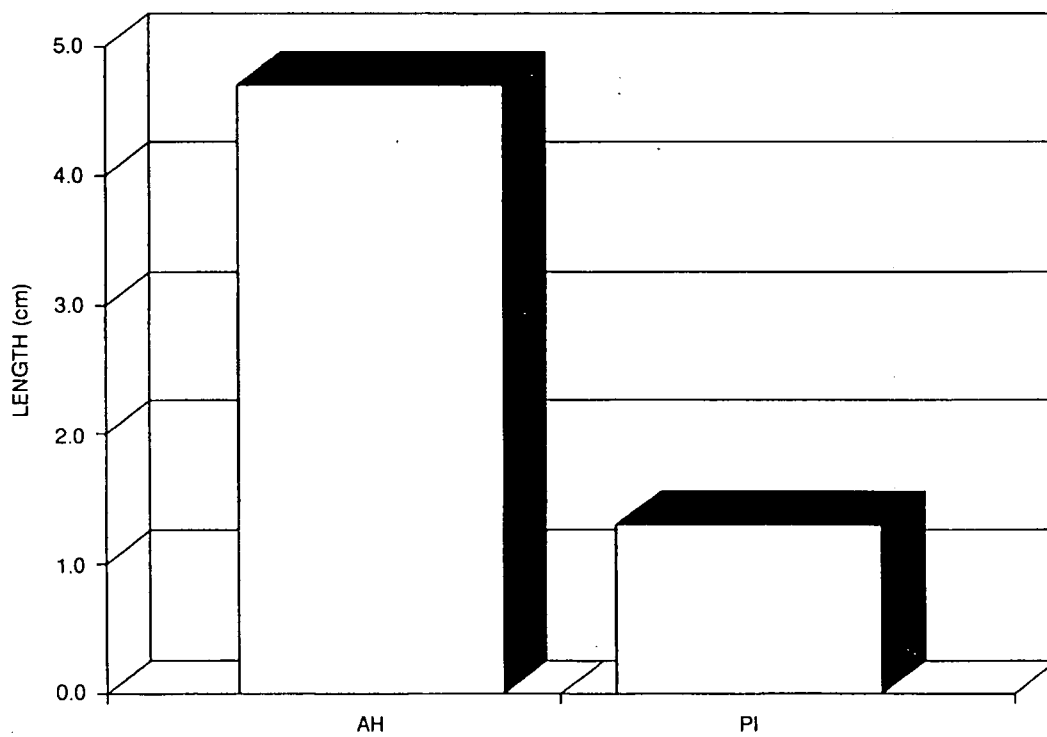
Figure 27. *Crassostrea* shell length.
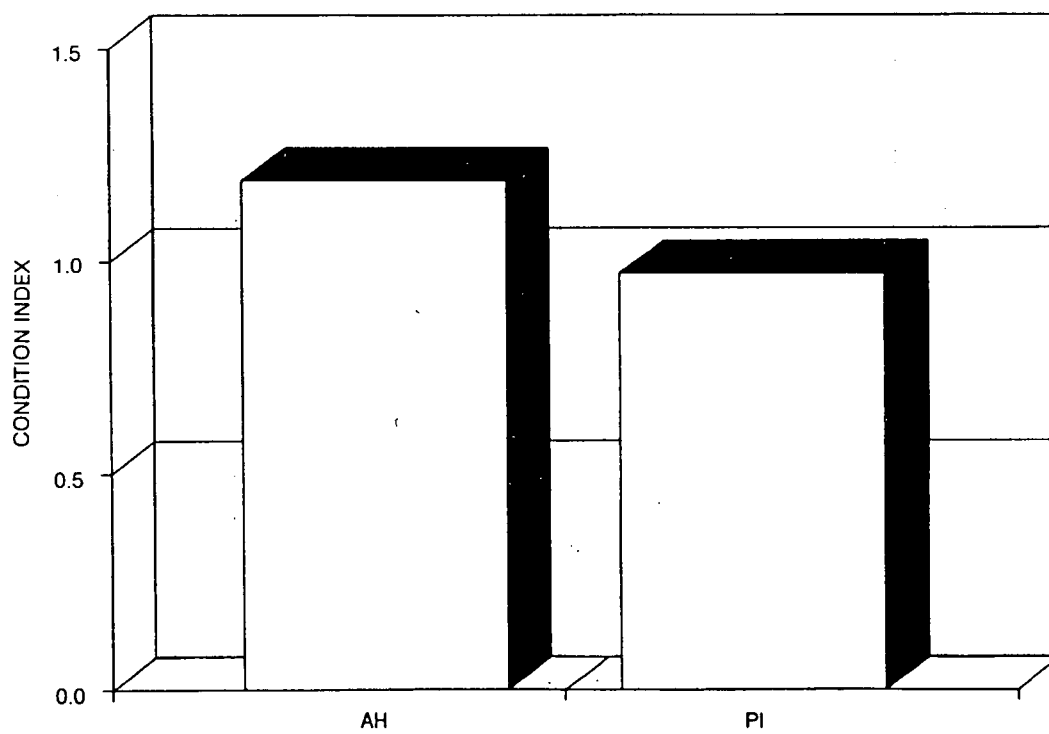
Figure 28. *Crassostrea* condition index.

Histopathology

Quahogs. All *Mercenaria* examined from the first two quarterly collections (December 1988 and April 1989) were in good health, with no significant pathologies observed. In contrast, pathology was observed in quahogs from all sites during the third quarter collection (July 1989). Specifically, 25.6% of quahogs examined contained parasitic mycoplasms (Family Mycoplasmataceae) in the digestive diverticula. The prevalence of mycoplasma infection decreased to 18.8% in the September sample (figure 29). The significance of this decrease is not clear, although it does appear to be a seasonal phenomenon. The fact that mycoplasma infection was found in quahogs throughout Narragansett Bay indicates that the condition is not specific to Allen Harbor.

Soft-Shell Clams. A number of pathological conditions were observed in *Mya arenaria* from all stations throughout this study (table 23). These included pathologies commonly associated with soft-shell clams, such as atypical cell hyperplasia (ACH) in the gills and kidney, and inflammatory responses. The incidence of kidney concretions,

Table 23. Pathology observed in *Mya arenaria*.

Pathology	Prevalence (%)										
	DEC 1988			APR 1989				JUL 1989			
	AH	MP	CC	AH	MP	CC	FDA	AH	MP	CC	FDA
Gill											
Inflammation (I)	76	28	84	44	57	58	46	88	37	70	88
Atypical Cell Hyperplasia (ACH)	56	40	8	41	12	15	38	71	33	26	63
Kidney											
ACH	28	48	44	89	92	88	58	71	67	33	63
Concretions	24	24	0	41	38	15	46	17	11	33	50
Intertubular Inflammation	0	0	8	0	0	0	0	0	0	0	0
Papilloma	0	0	0	4	0	0	0	0	0	0	0
Epithelioma	0	0	0	0	0	8	0	0	0	0	0
Heart											
Myxoma	0	0	0	11	4	4	0	0	7	0	0
Mesothelioma	0	0	0	4	0	0	0	0	0	0	0
Tumor	4	8	0	0	0	0	0	0	0	0	0
Swollen Muscle Bundles	0	12	0	0	0	0	0	0	0	0	0
Papilloma	0	0	0	0	0	4	0	0	0	0	0
Inflammation	0	0	0	0	0	0	0	4	0	0	0
Parasites											
Worms	12	36	48	0	0	0	0	0	0	0	0
Protozoa (Kidney)	0	8	0	0	0	0	0	0	0	0	0
Protozoa	0	4	0	0	0	0	0	0	0	0	0
Parasites (Unidentified)	0	0	0	7	62	69	42	33	33	22	0
Other											
GI Tract - Inflammation	4	0	0	0	0	0	0	0	0	0	0
L. Palps - Inflammation	12	0	0	0	0	0	0	0	0	0	0
Mantle - Inflammation	8	0	40	0	0	0	0	0	0	0	0
- Foci of metaplasia of pallial cell	4	0	0	0	0	0	0	0	0	0	0
Mouth - Ulceration	4	0	0	0	0	0	0	0	0	0	0
Nerve fibers - Swollen	8	0	0	0	0	0	0	0	0	0	0
Stomach - Ulceration	4	0	0	0	0	0	46	0	0	0	0
- Papilloma	0	0	0	4	0	0	0	0	0	0	0
Digestive Diverticula - Mycoplasms	0	0	0	15	19	27	0	13	7	4	0
Hematopoietic neoplasia (HN)	4	12	0	7	8	،0	29	8	19	0	0
Connective tissue - inflammation	4	0	0	4	8	0	0	0	0	0	0
Red Gland - Epithelioma	0	0	0	4	0	0	0	0	0	0	0
D Ducts + tubules - necrosis	0	0	0	0	0	0	13	0	0	0	0

parasitism, and mycoplasma infection varied seasonally across sampling periods, but generally existed at all sites within a given sampling period.

Neoplastic lesions associated with the heart and hematopoietic system were found in clams collected in Allen Harbor and at FDA and Marsh Point, but not at Coggeshall/Sheep Pen Cove (figure 30). The greatest incidence of hematopoietic neoplasia (HN, leukemia, or sarcoma) was found in clams collected from the FDA station during April. Within Allen Harbor, the highest incidence was found at station AH13 (figure 31). The presence of HN within Allen Harbor was not unexpected. Brown et al. (1977) and Cooper, Brown, and Chang (1982) reported affliction rates ranging from 19 to 43% for soft-shell clams collected in Allen Harbor from July 1977 through March 1979. These studies also identified seasonal peaks in HN in April and October/November. Our results also indicate peak prevalence in April (figure 31). Cooper, Brown, and Chang (1982) reported that HN may sometimes be progressive and lead to the death of the organism, although *Mya* densities in our study were highest in AH (see figure 21).

HN has been found in soft-shell clams throughout the western shore of Narragansett Bay, although historically the highest rates were observed in Allen Harbor (Brown 1977; Brown et al., 1976, 1977, 1979; American Petroleum Institute, 1984). Episodic incidences of the disease have been reported in New Bedford Harbor, MA (Reinisch et al., 1984), Long Island Sound (Brousseau, 1987), and Chesapeake Bay (Farley, Otto, and Reinisch, 1986). Although its etiology is not well understood, Oprandy et al. (1981) report the isolation of a viral agent believed to be responsible for this neoplasia. The role of pollution as a factor in the occurrence of the disease is not clear (Saila, Lorda, and Walker, 1979; Walker, Lorda, and Saila, 1981; American Petroleum Institute, 1984; Farley, Otto, and Reinisch, 1986), although there is evidence to implicate certain toxicants in promotion of the disease (Reinisch et al., 1984; Farley et al., 1991). Activities during Phase II of this project will address the spatial distribution of HN in western Narragansett Bay.

Oysters. A histological examination of *Crassostrea virginica* collected in Allen Harbor and at Prudence Island revealed no pathology in either sample. All organisms were in good to excellent health.

Sediment Effects

Amphipod Mortality.

Subtidal Sediments. No ecologically meaningful mortality was observed in sediments collected from subtidal Allen Harbor or bay stations (figure 32), nor were differences observed (ANOVA, P=0.05) between control CLIS sediments and any subtidal sediment. The lack of toxicity rendered statistical analysis of among-station differences meaningless.
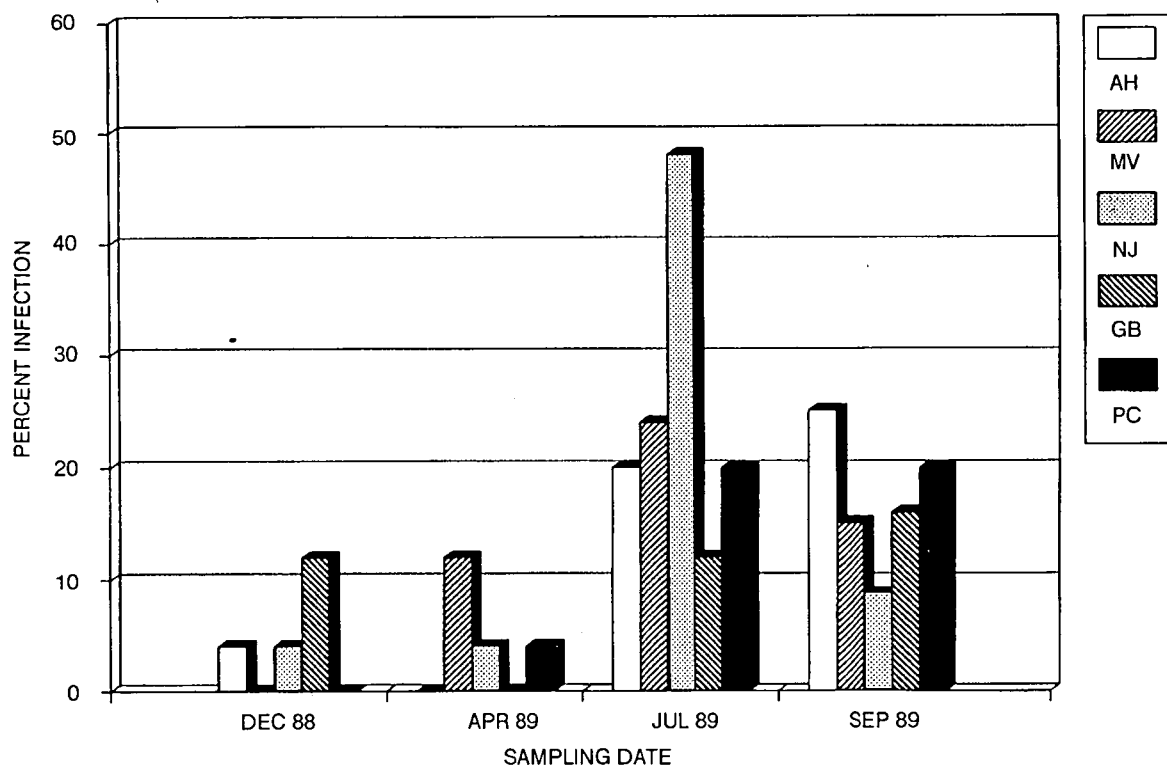
Figure 29. Mycoplasm infection rate in *Mercenaria*.
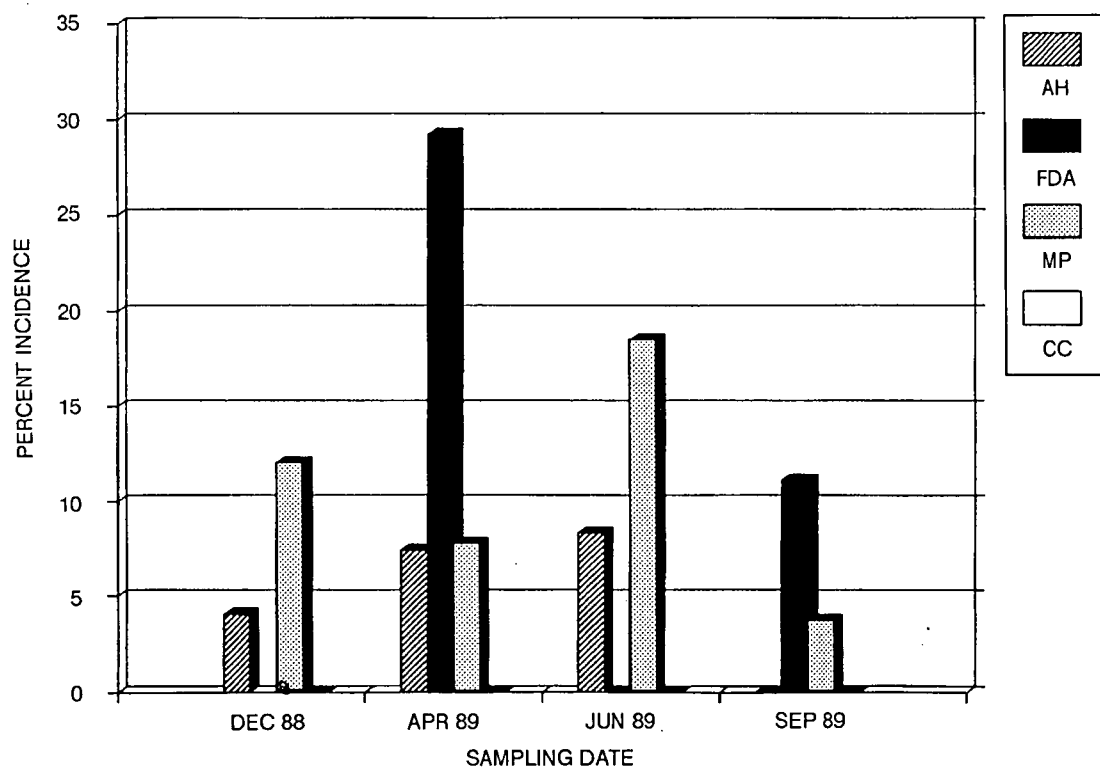
Figure 30. Hematopoietic neoplasia affliction rate in *Mya* at Narragansett Bay stations.
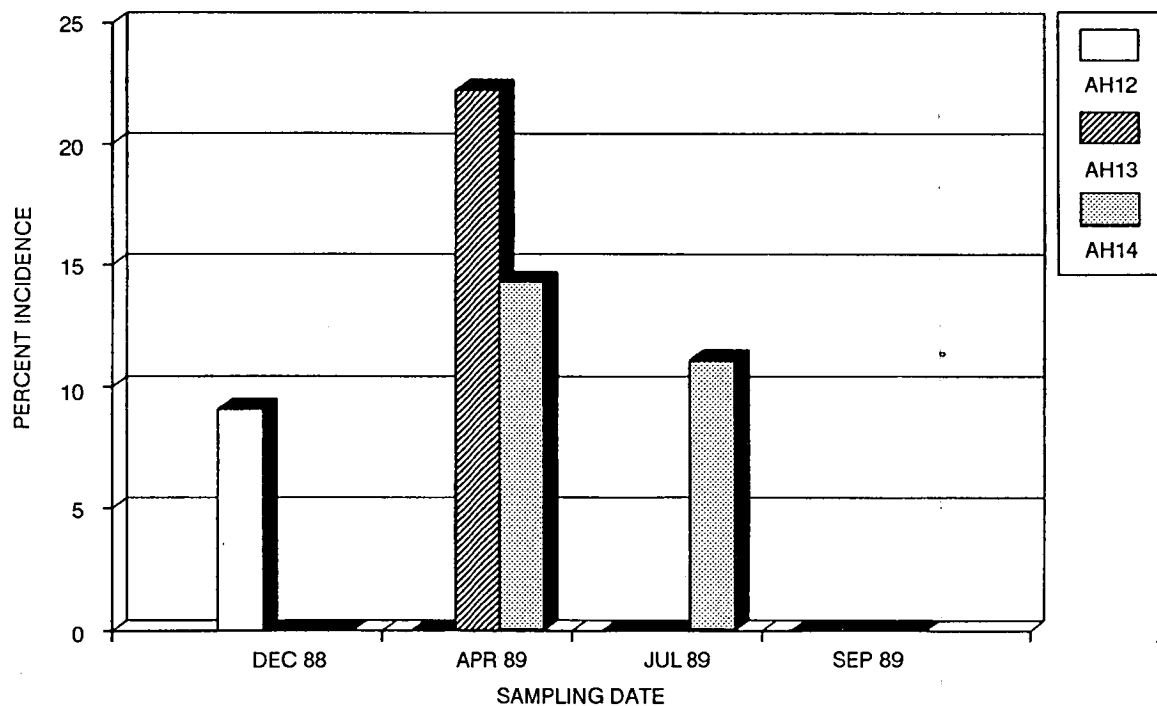
Figure 31. Hematopoietic neoplasia affliction rate in *Mya* at Allen Harbor stations.
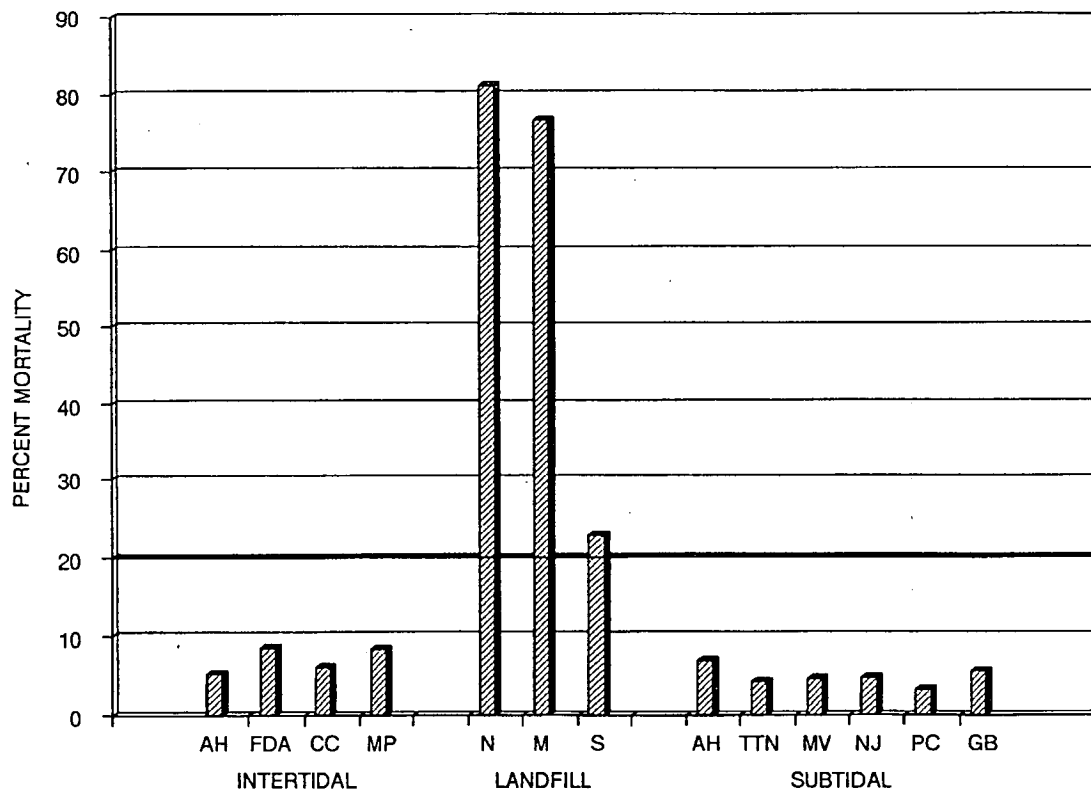
Figure 32. Results of amphipod sediment toxicity bioassays.

The 8 stations tested within Allen Harbor exhibited uniformly low toxicity (figure 32), indicating little effect from the landfill or Calf Pasture Pt. Similarly, the lack of toxicity associated with the TTN transect outside the harbor indicated little recent migration of toxic constituents from the harbor into Narragansett Bay.

Intertidal Sediments. As observed for subtidal sediments, none of the intertidal sediments produced mortality greater than 20% (figure 32), nor were significant differences observed (ANOVA, P = 0.05) between any station and the CLIS control sediment.

Landfill Material. Significant mortality was associated with material collected from the north, middle, and south faces of the landfill exposed to *Ampelisca* (figure 32). Extreme mortality of 81.1% and 76.7% resulted from exposure to sediments from the north and middle faces, respectively. South face material caused less mortality, affecting 22.7% of the animals exposed. Although extremely suggestive of landfill-associated contaminant effects, material from all three sites was composed primarily of "large stones, medium to small...gravel, bits of metal and broken glass."[*] Sediment grain size is known to affect amphipod mortality in laboratory assays, and *Ampelisca* requires fine grain sediment for normal survival. The implication, therefore, is that these toxicological analyses were confounded by a grain size effect.

Biomarker Responses.

Sister Chromatid Exchange. In the absence of S9 enzyme activation, neither Allen Harbor nor Mount View sediments elicited significant mutagenic effects as determined by SCE response (figure 33). When activated with the S9 rat liver microsomal fraction, however, both sediments induced a significant response (figure 34). Under these conditions, Allen Harbor extracts were the more mutagenic: 0.33 grams dry weight of sediment extracted into 1 ml of exposure medium induced the same response as approximately 0.53 grams of MV material (figure 34).

These results generally reflect the PAH concentrations observed at the two sites. Concentrations in Allen Harbor sediment were typically 2-3 times those found at Mount View. PAHs are potential promutagens capable of inducing SCEs, but they require metabolic transformation to mutagenic forms. Similar results were observed in previous studies with BRH and CLIS sediments, in which metabolized extracts were significantly more mutagenic than nontransformed extracts (Gardner et al., 1987). The mutagenic potential of these sediments (figure 35) correlates well with their respective PAH concentrations.

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[*] K. McKenna, SAIC, personal communication.
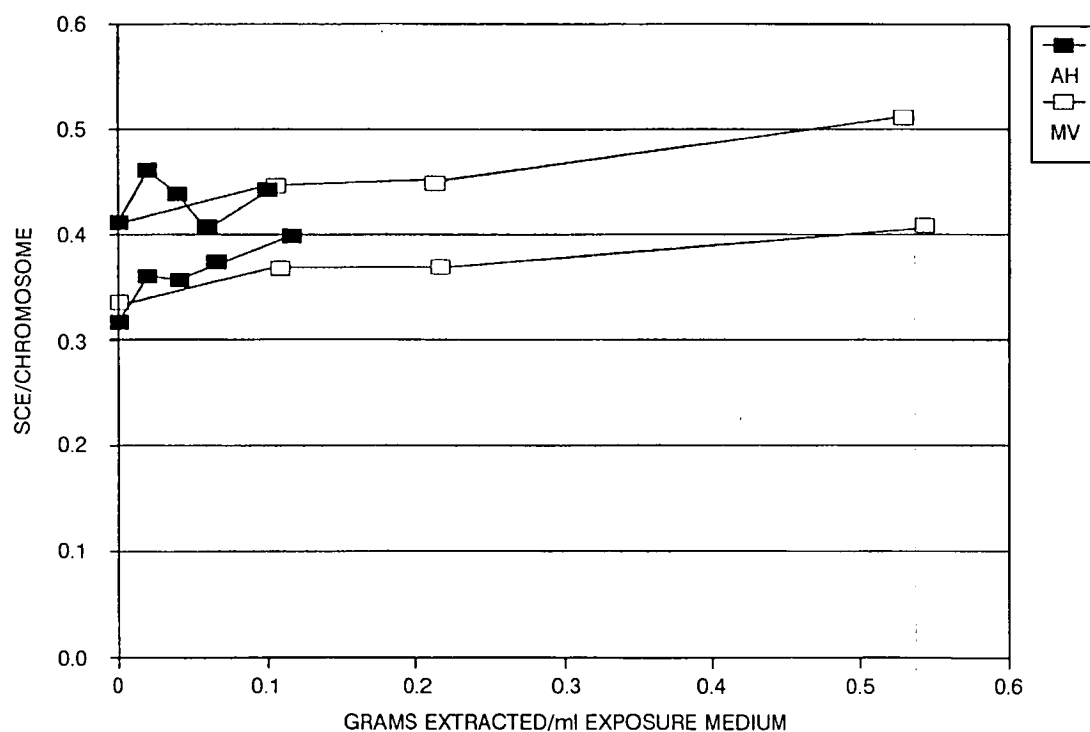
Figure 33. Results of sister chromatid exchange assays of sediment extracts without S9 enzyme activation.
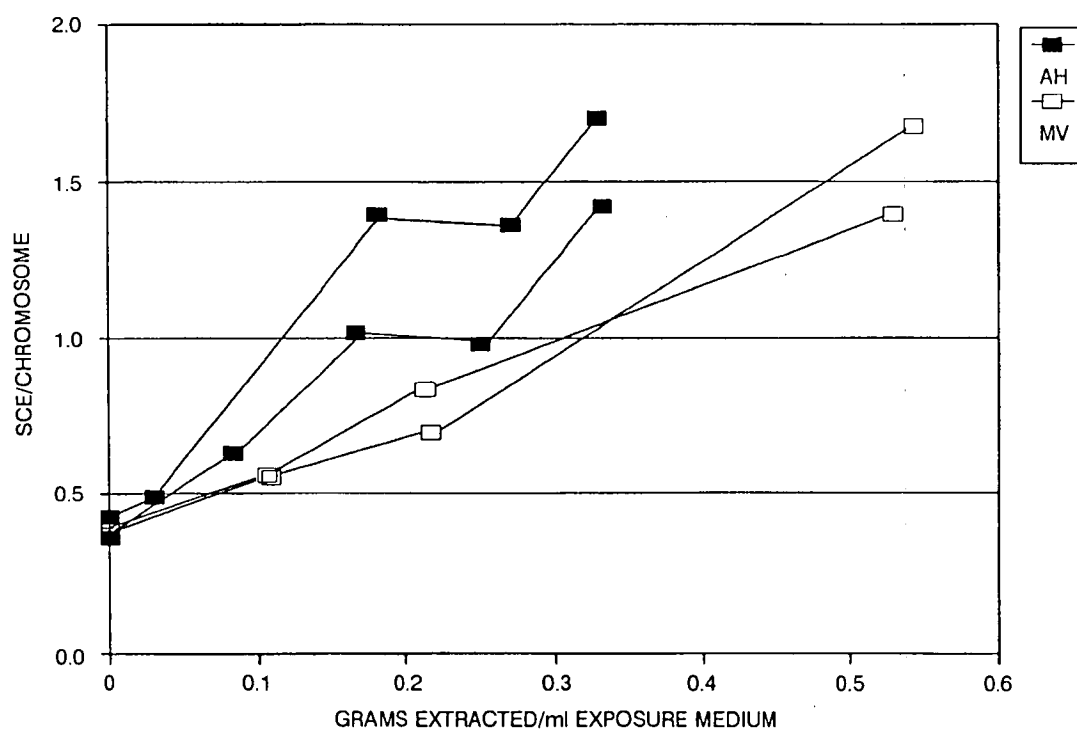
Figure 34. Results of sister chromatid exchange assays of sediment extracts with S9 enzyme activation.

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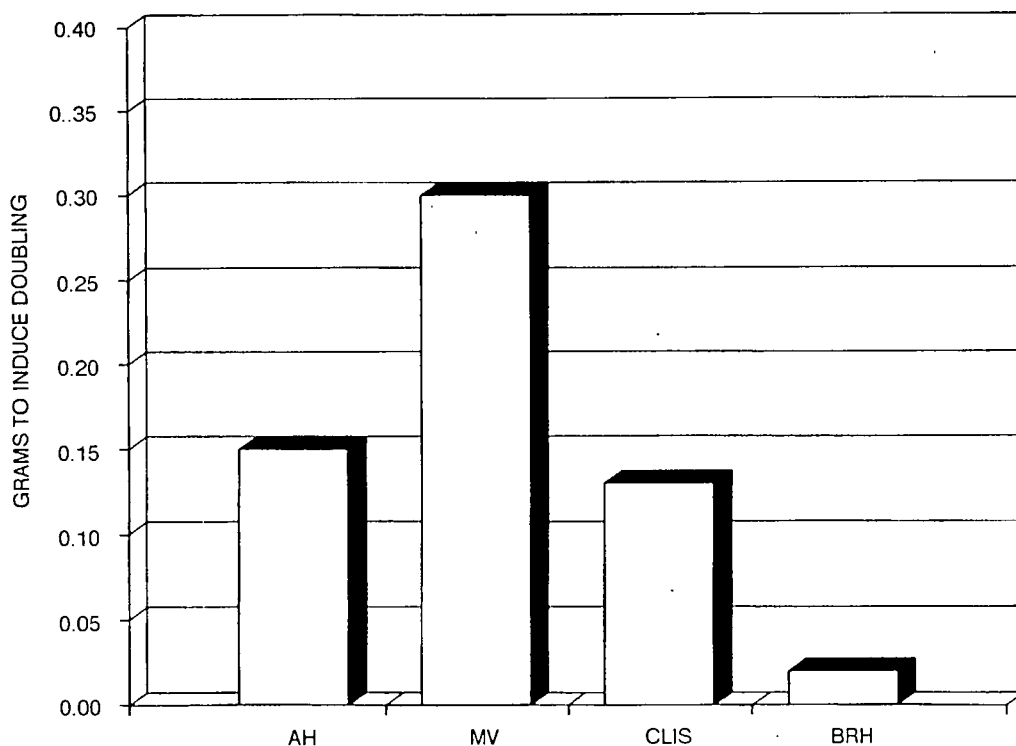
Figure 35. Comparison of sediment potency in inducing
a significant sister chromatid exchange response.

V79/Metabolic Cooperation. No significant increase in mutant cell recovery was observed in replicate experiments with Allen Harbor or Mount View whole sediment extracts (figure 36), nor were increases in mutant colony recovery observed in assays of Allen Harbor and Mount View extract fractions (figures 37–40). These results suggest three possible situations: (1) no tumor-promoting chemicals were present in the sediment extracts, (2) any tumor-promoting chemicals in the sediment extracts were present in concentrations too low to be detected in this assay; or (3) any activity of tumor-promoting chemicals present in the extracts was masked by the presence of other substances in the mixture. The available data do not provide insight as to which of these possibilities is the most likely.

Sea Urchin Fertilization, Development, and Survival. Allen Harbor and Mount View whole sediment extracts affected *Arbacia* fertilization, growth (length) and survival equivalently (figure 41). Significant differences were found between 0.2% concentrations of both AH and MV, and the control treatments. Significant decreases from control treatments were also observed in the length and survival of 48-hour pluteus larvae exposed to concentrations of 0.05 and 0.2% MV extracts and at a 0.2% concentration of AH. Additionally, the 0.05% concentration of AH retarded the growth of *Arbacia* larvae.
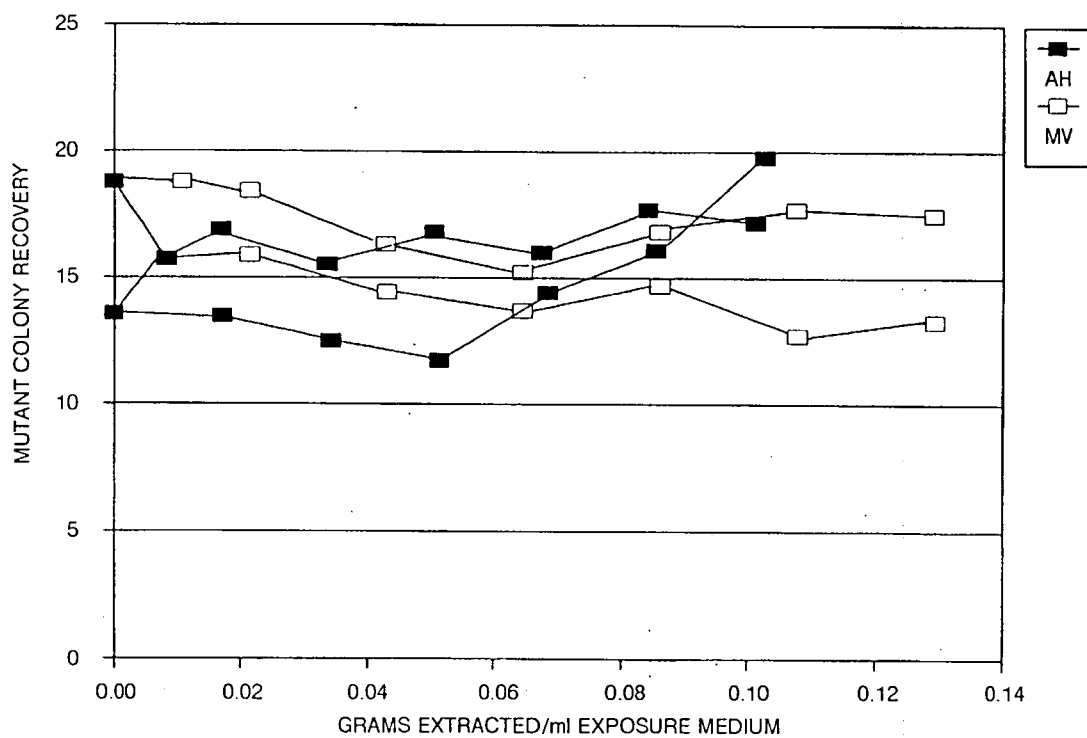
Figure 36. Results of V79/metabolic cooperation assays of whole sediment extract.
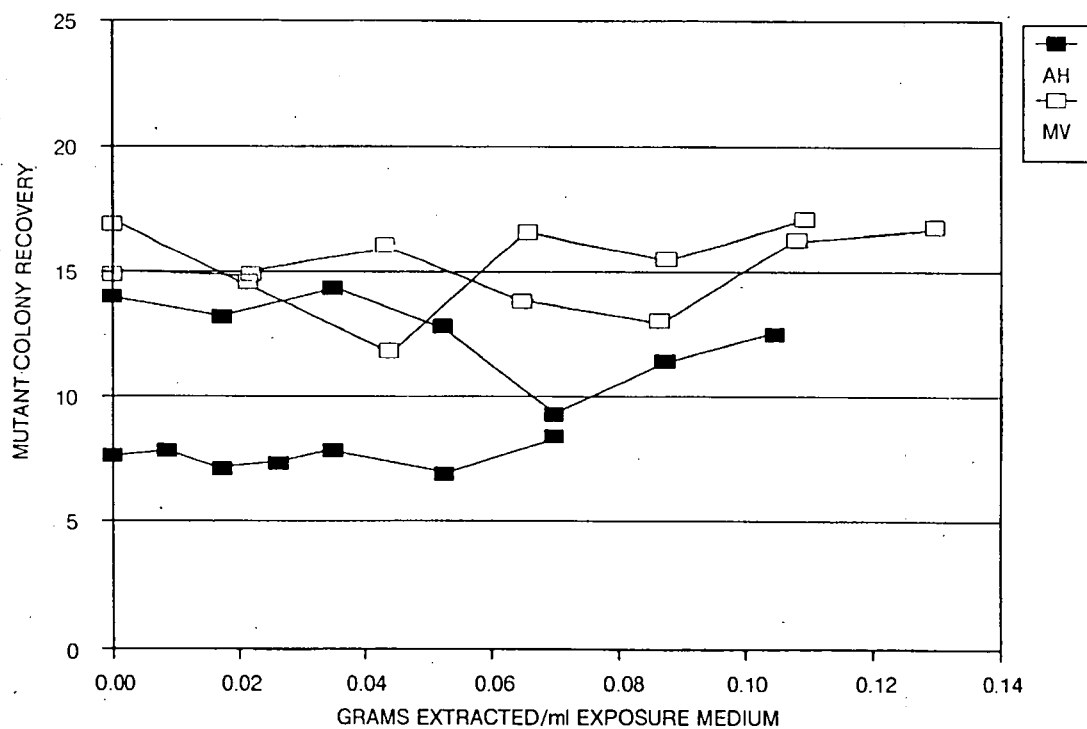
Figure 37. Results of V79/metabolic cooperation assays of the f_1 fraction of sediment extract.
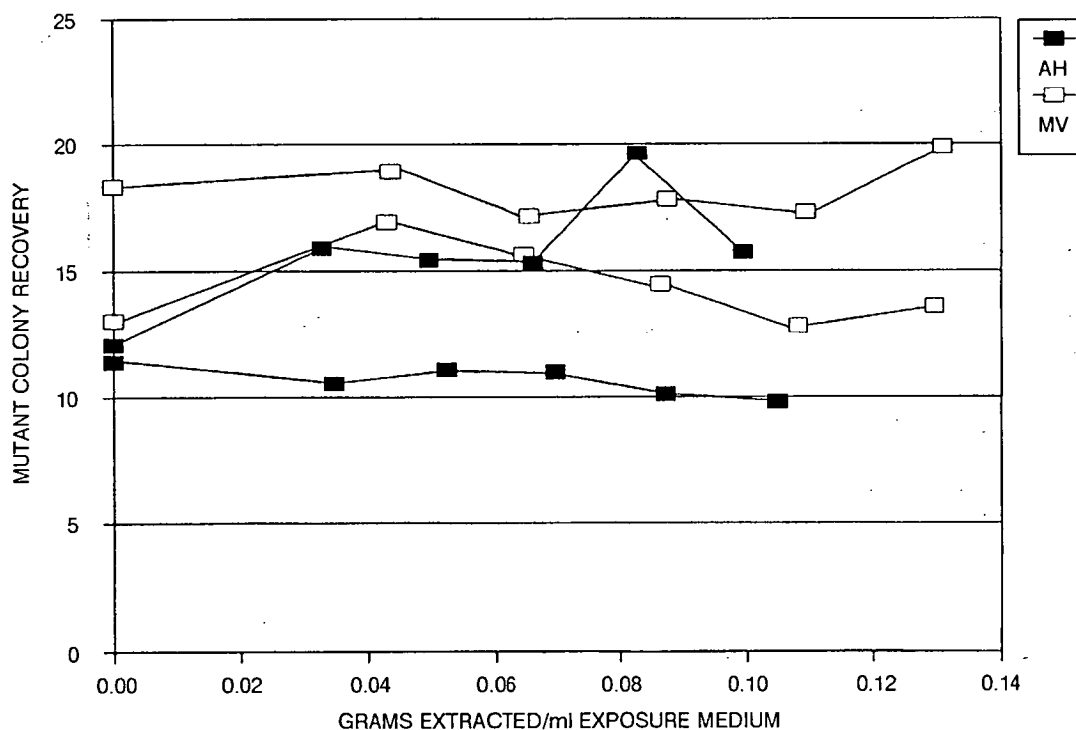
Figure 38. Results of V79/metabolic cooperation assays of the f_2 fraction of sediment extract.
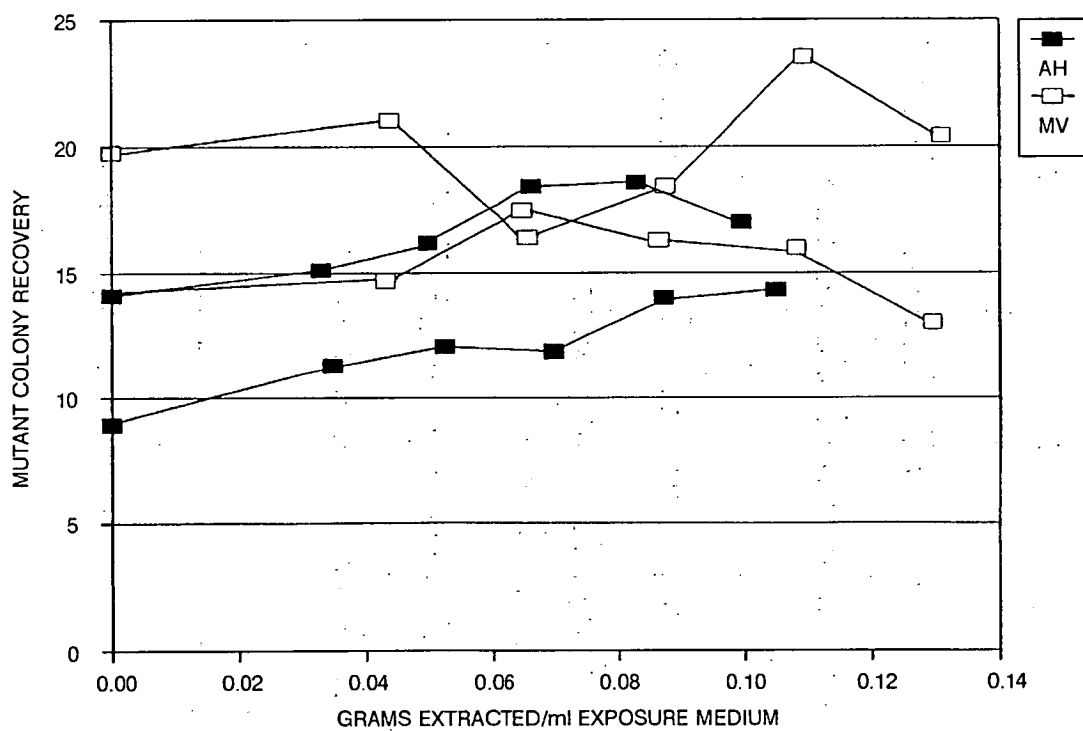
Figure 39. Results of V79/metabolic cooperation assays of the f_3 fraction of sediment extract.
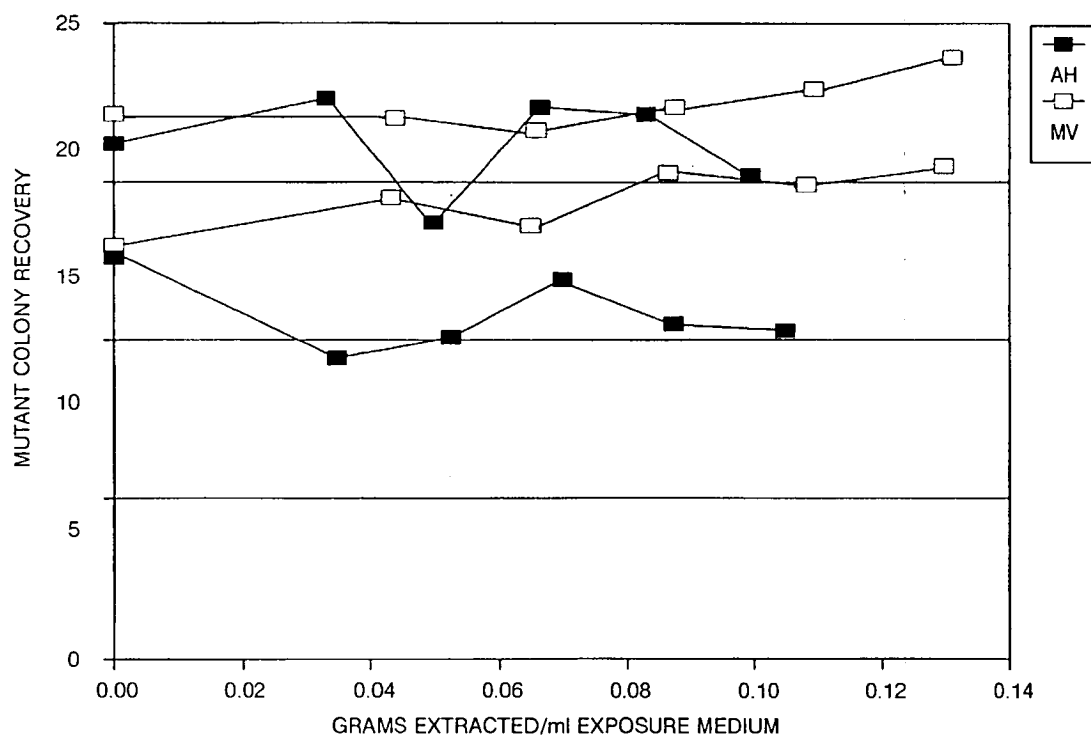
Figure 40. Results of V79/metabolic cooperation assays of the f$_4$ fraction of sediment extract.
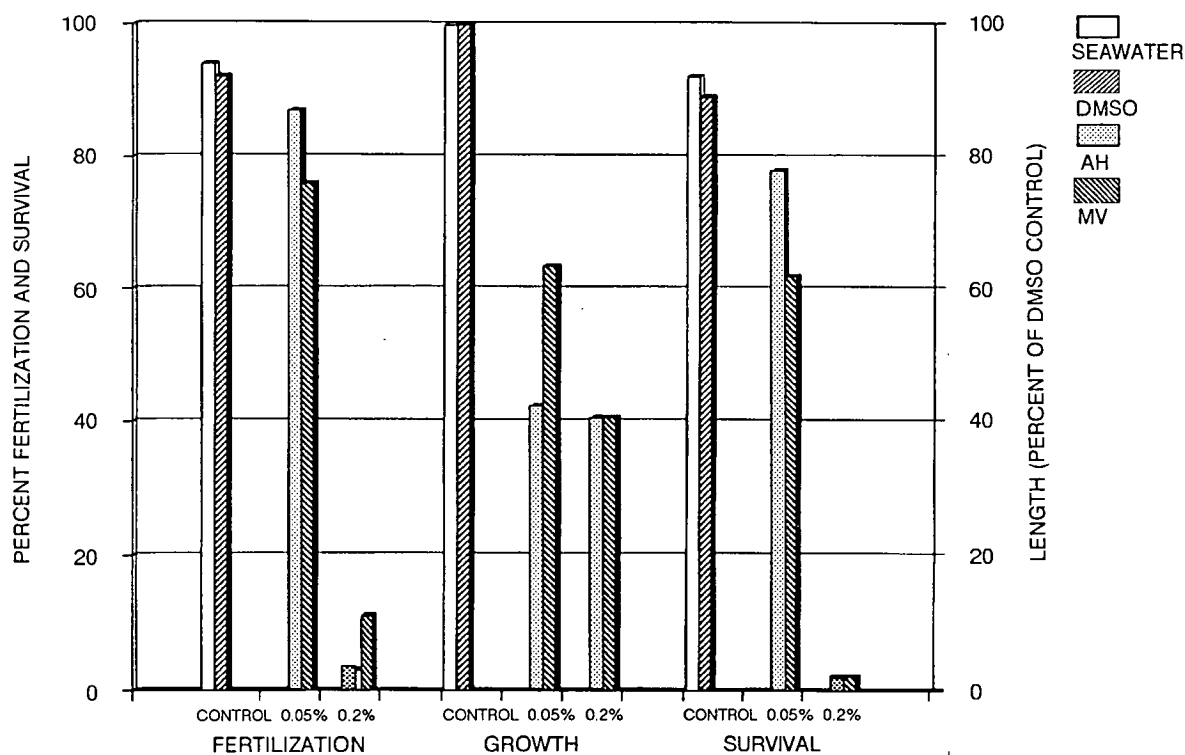
Figure 41. Results of sea urchin bioassays of whole sediment extract.

Contrary to results obtained using sediment extracts, Allen Harbor interstitial water was substantially more toxic to sea urchin fertilization, growth, and survival than was Mount View interstitial water (figure 42). However, even at a concentration of 50% MV extract, significant decreases were detected in growth relative to seawater controls. No fertilization was detectable at AH extract concentrations greater than 12.5%.
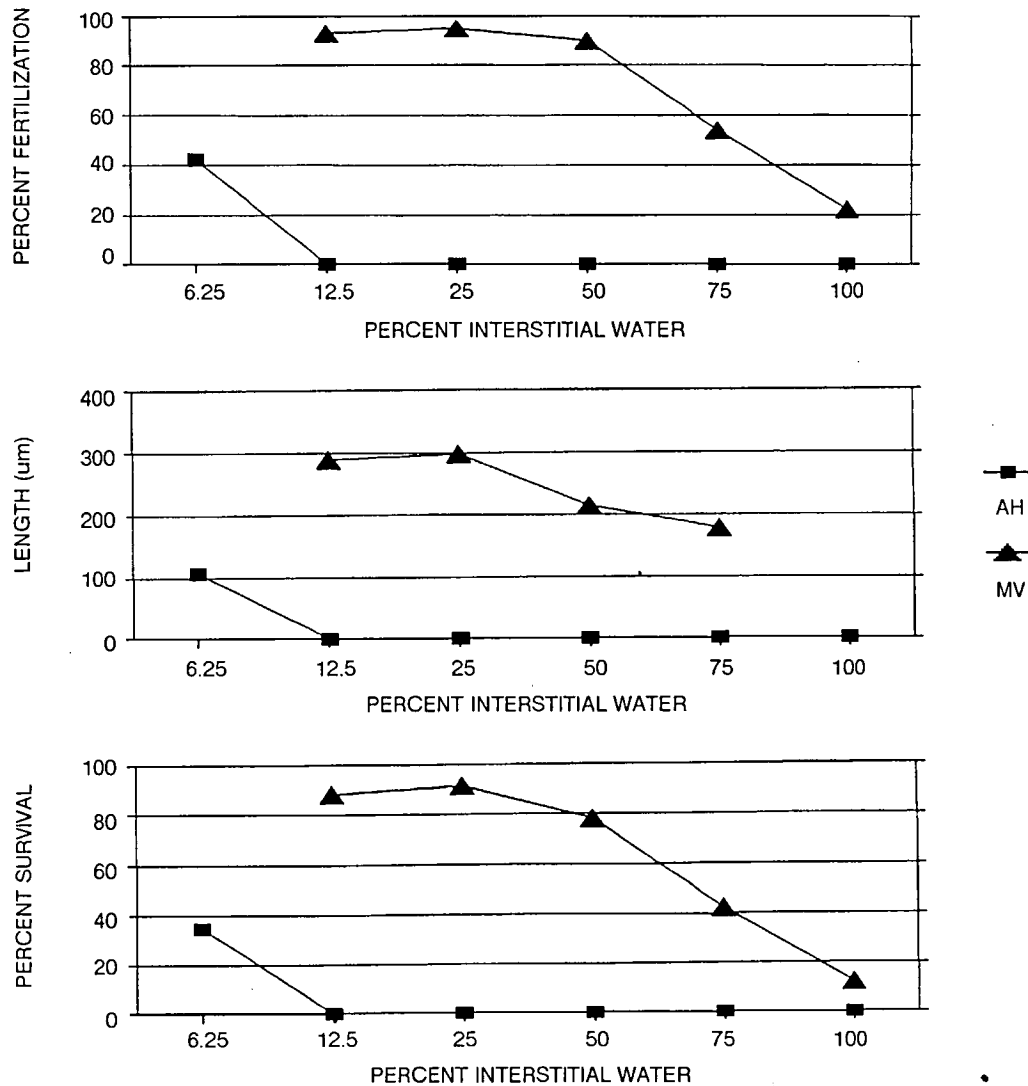
Figure 42. Results of sea urchin bioassays of interstitial water.

Benthic Community Condition. Information obtained using the REMOTS technology at the Narragansett Bay Project's three Allen Harbor stations is summarized in table 24. Using the designations given in SAIC (1989), sediments at AH-1 and AH-2 consisted primarily of silt/clay-sized particles (Phi >4). Station AH-3 exhibited a mode of very fine sand (Phi 4-3) and was characterized as consisting of "compact medium to fine sand and very fine sands mixed with silt-clay" (SAIC, 1989). Although the exact

locations of these stations within the harbor are unclear, these observations are supported by the grain size analyses described earlier (see figure 10).

Dissolved oxygen levels, although somewhat depressed from saturation concentrations, were all greater than 3.0 ppm, the level generally cited for oxia. On the other hand, Stations AH-1 and AH-3 had mean apparent sediment redox-potential depths (RPD) of 0.0 cm; Station AH-2 had a mean apparent RPD of 1.32 cm. A depth of <3 cm is considered critical (SAIC, 1989). These depressed values may reflect chronic disturbance caused by shellfishing, organic loading, or other physical or chemical activity. *Clostridium* counts were uniformly low, particularly compared to stations located near the discharges of sewage treatment plants.

Table 24. Benthic community condition in Allen Harbor as determined by REMOTS technology (summarized from SAIC, 1989).

Parameter	Station[a]		
	AH-1	AH-2	AH-3
Granulometry (Phi)	>4	>4	4–3
Dissolved Oxygen (ppm)	4.6–5.2	6.0–6.1	3.3–4.4
RPD[b] (cm)	0.0	1.32	0.0
Clostridium Count	low	low	low
Organism-Sediment Index	1.8	4.8	nm[c]

[a] Station designations used in SAIC (1989).
[b] RPD = apparent redox-potential depth.
[c] nm = not measured.

These measurements, when combined with the REMOTS camera observations of indigenous benthic community composition and structure, were used to calculate an Organism-Sediment Index (OSI; SAIC, 1989). A healthy, fully developed community results in an OSI >6. Stations AH-1 and AH-2 exhibited values below this level (1.8 and 4.8, respectively). Sediments at AH-3 were too compact to permit sufficient penetration of the benthic camera for OSI estimation. Despite their apparent depression, these levels compare favorably with the negative values found at Apponaug Cove, Potowomut River, Greenwich Cove, and the Providence River (SAIC, 1989), all of which are characterized as having excessive organic loading. Thus, although the Allen Harbor stations were at an early successional stage ("dominated by azoic Stage I and Stage II series") due to chronic disturbance, they were rated as among the lesser degraded of the 56 stations in the Narragansett Bay study.

Water-Column Effects

Deployed Mussel Physiological Condition. *Mytilus edulis* deployed in Allen Harbor in May–June showed both a lower clearance rate and a higher respiration rate than did

mussels deployed at the Narragansett Bay stations (table 25). Assimilation efficiency was equivalent across stations. When integrated into the SFG index, these rates indicated a significantly reduced physiological condition for Allen Harbor mussels (figure 43). The remaining stations did not differ with respect to SFG.

Table 25. Physiological condition of *Mytilus edulis* following the spring deployment.

Station	Clearance Rate (L/h)	Assimilation Efficiency (%)	Respiration Rate (ml/h)
AH	2.3 A	93 A	0.85 A
TTN	3.9 B	94 A	0.56 B
MV	3.9 B	97 A	0.53 B
LAB	3.5 B	96 A	0.52 B

Note: Means designed with similar letters are not statistically different (P<0.05).

The chemical analysis of the soft tissues of these animals (see table 20) is equivocal with respect to the causes of the observed differences in physiological response. Although numerous compounds have correlated well with SFG in previous studies (e.g., Nelson et al., 1987), single contaminants cannot be implicated as the causative agent. AH mussels grouped with stations exhibiting the highest residue means in six of the seven cases for which station differences were observed, yet concentrations were never significantly greater than those of all other stations. It may be that elevations in a suite of compounds were responsible for the physiological effect.

Mussels exposed during the fall deployment in September–October also exhibited differences in clearance and respiration rates with respect to station (table 26). These differences translate into SFG estimates which were depressed at AH and TTN relative to the SFG estimate at LAB (figure 43). Numerical results associated with the two deployments cannot be compared because of a variation in hydrographic parameters, such as temperature, which can dramatically influence physiological rates.

Table 26. Physiological condition of *Mytilus edulis* following the fall deployment.

Station	Clearance Rate (L/h)	Assimilation Efficiency (%)	Respiration Rate (ml/h)
AH	1.3 A	70 A	0.44 A
TTN	2.1 A, B	59 A	0.66 B
LAB	4.1 B	71 A	0.47 B

Note: Means designed with similar letters are not statistically different (P<0.05).
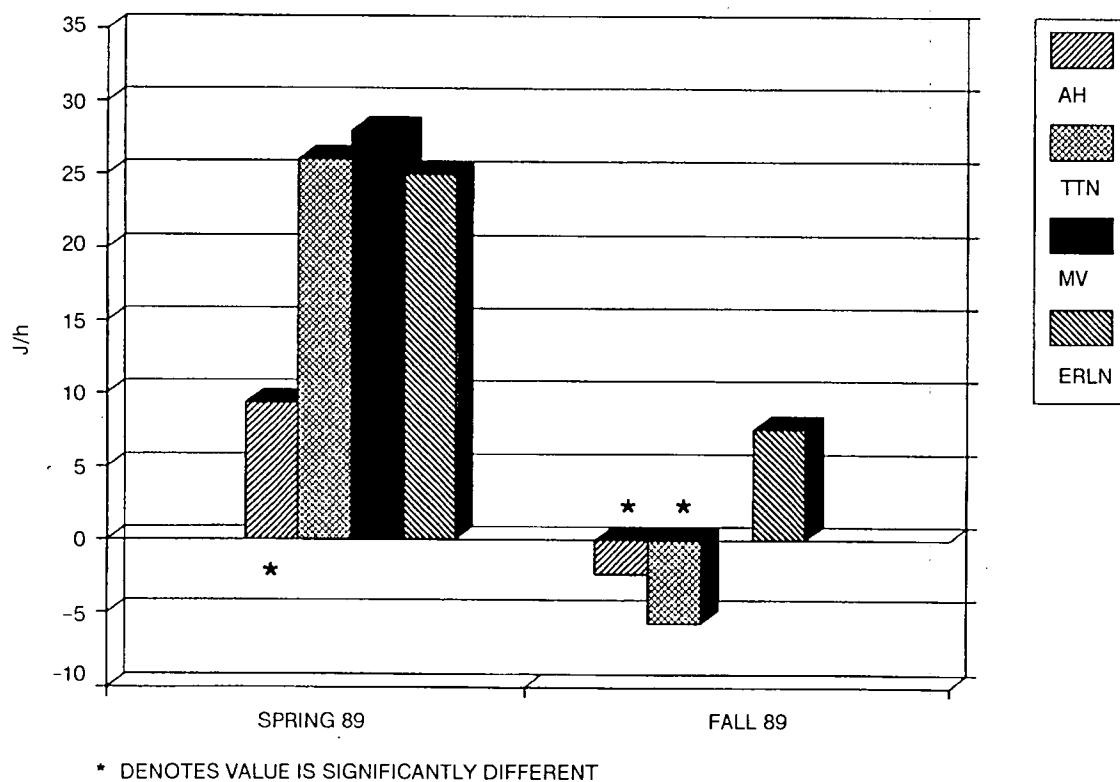
Figure 43. Scope for growth index of deployed *Mytilus*.

The consistently low clearance rate and SFG integration observed in Allen Harbor mussels indicates a water quality problem. Phase II activities are designed to further define water quality in the harbor and to elucidate the sources of water column toxicity.

Deployed Mussel Immunological Response. No differences were observed in the *in vivo* immunological response of *Mytilus edulis* deployed in Allen Harbor and at LAB (figure 44). Although the activity of phagocytic cells was slightly depressed in AH mussels, the variability in response between animals was fairly high. Increased sample sizes should be taken to detect any existing differences.

Deployed Mussel Pathology. Tissues of *Mytilus edulis* deployed during June 1989 were examined to identify histological correlates to the patterns observed in physiological response (e.g., Nelson et al., 1987; Yevich et al., 1986). However, no pathology was observed in animals deployed at any of the four sites.
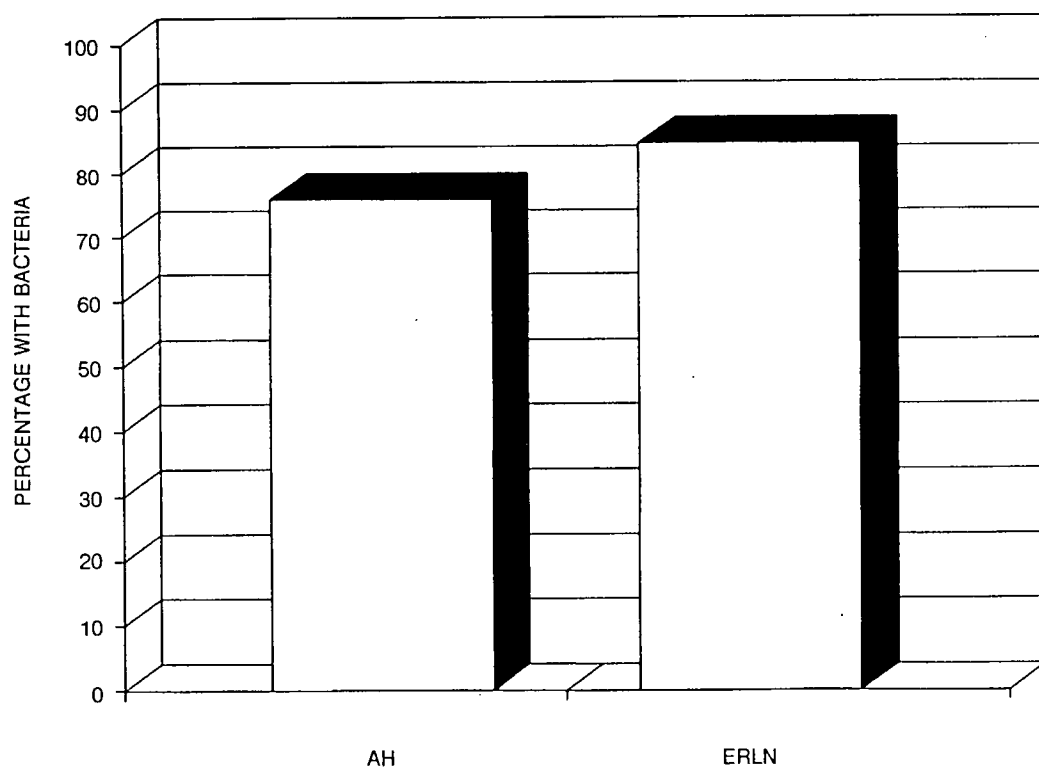
Figure 44. Results of phagocytic index assays of deployed *Mytilus*.

PRELIMINARY ASSESSMENT OF ECOLOGICAL RISK

In its broadest definition, ecological risk assessment involves the quantitative estimation of the likelihood of adverse ecological effects resulting from existing environmental conditions or from changes in those conditions. Ideally, the risk estimation procedure involves the development of statements of the probability of changes in state (for example, in reproductive status or population growth rate) or of the occurrence of some event (such as death, population extinction, or ecosystem collapse). Such is the case in human health risk assessments, where mechanisms involved in disease etiology may be understood with some degree of confidence. As a result of this understanding, procedures have been developed for quantifying changes in the rate of cancer formation which are more or less generally accepted (e.g., PTI, 1987).

Despite their obvious value to environmental managers, estimation procedures for the quantification of ecological risk are not developed as fully as those addressing human health. Much of the difficulty in their development results from an incomplete understanding of ecological mechanisms and relationships. Thus, ecological risk assessment is a rapidly evolving field with little standardization. Certain approaches have received greater acceptance, however. Perhaps the most straightforward and widely used of these are the various quotient methods (see Barnthouse et al., 1986; U.S. EPA, 1986, 1988). In brief, these methods compare expected environmental concentrations (EECs) to toxicological benchmark concentrations (BCs) through the formation of a risk quotient (RQ):

$$RQ = EEC/BC$$

EECs are typically evaluated through field sampling activities or may be based on model calculations. Examples of useful BCs include LC_{50} concentrations, no observable effect levels (NOELs), and threshold concentrations determined for single contaminants or complex mixtures in laboratory studies, as well as any other "applicable or relevant and appropriate requirement" (ARAR) mandated by environmental statutes. Critical values of RQ are established which reflect perceived risk; generally, a ratio greater than unity would indicate a high risk of adverse effects.

Other, more complicated or data-intensive approaches to risk assessment are also appropriate. These include exposure-response methods (EPA, 1988), which involve the detailed description of biological response to exposure concentration expressed on a continuous scale. With a knowledge of exposure concentrations in time or space, risk can be quantified as the intersection of two probability distributions. Figure 45 illustrates this approach conceptually. The quantification of the actual risk of a particular level of response is based on the variability in the response itself, as well as on other stochastic processes (e.g., Munns, Walker, and Paul, 1989). Simulation techniques (e.g., Monte Carlo methods) are often useful in characterizing risk with these approaches.
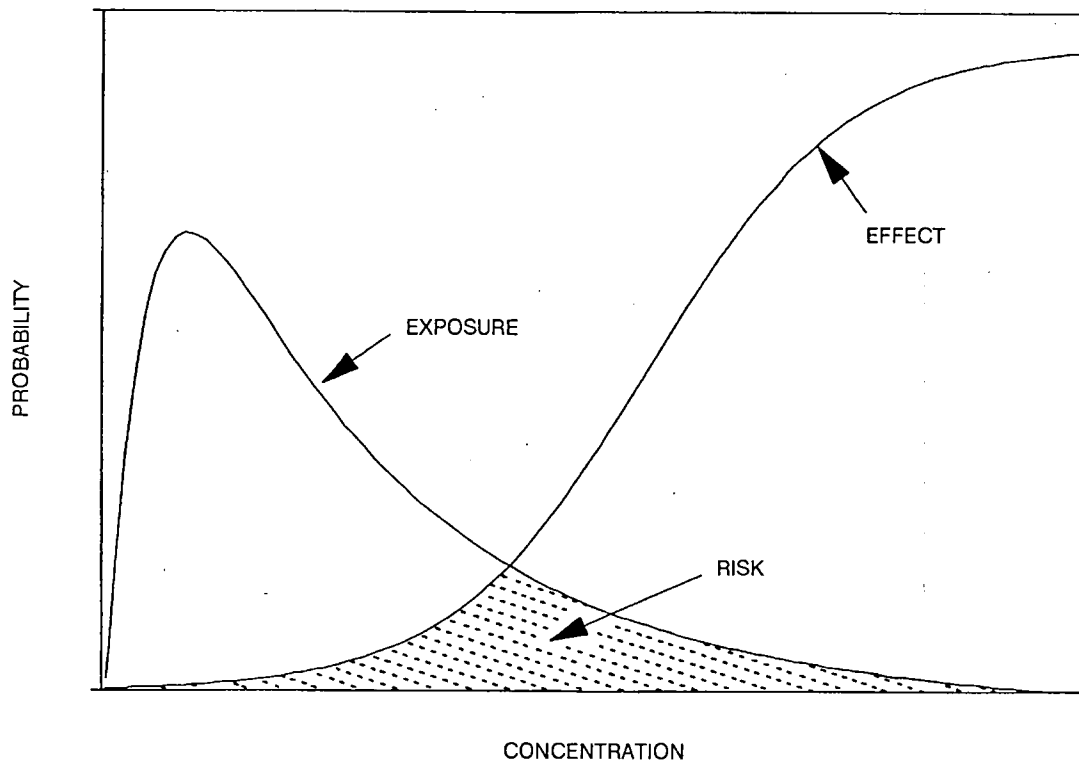
Figure 45. Conceptual continuous exposure-response model of quantitative ecological risk assessment.

APPLICATION OF THE RISK QUOTIENT METHOD

Because of its relative ease of application, and the increasing availability of acceptable BCs, a quotient method approach is appropriate in preliminary assessments of ecological risk such as this. In the following analysis, sediment and water column EECs based on the field measurements were compared with several benchmarks of sediment and water quality. For sediments, these benchmarks included Long and Morgan's (1990) Effects Range-Low (ER-L) concentrations, developed to compare National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program sediment data. ER-L concentrations represent the lower 10 percentile of all concentrations of an individual contaminant observed over a range of studies to cause biological effects (see Long and Morgan, 1990 for details). This statistic is somewhat similar in concept to the lowest observed effect level (LOEL), the lowest toxicant concentration observed in bioassays to produce biological effects. A second sediment benchmark applied here is the benthic community composition Apparent Effects Threshold (AET) concentration, developed for individual contaminants in field sediments as reported by PTI (1988). These concentrations represent the level of individual chemicals above which statistically significant biological effects are always expected to occur, and are derived from a fairly extensive set of field surveys in the Puget Sound,

Washington, region. Both sets of benchmark concentrations are conservative, in that they represent the lower end of the range of concentrations having been associated with field effects. The ER-L approach is the more conservative of the two, identifying levels of individual contaminants typically an order of magnitude lower than the corresponding AET. An advantage of both approaches lies in their assessment of chemical effects in natural mixtures of environmental contaminants. Sediment benchmark concentrations for contaminants measured in this study are given in table 27.

The water column benchmark selected for use here is EPA's Chronic WQC for marine waters. Rhode Island has adopted these criteria for regulatory purposes. Unfortunately, the list of contaminants for which marine WQC have been developed overlaps little with the list of those measured in this study, as indicated in table 28.

Levels of risk were defined relative to the risk quotient as—

$$RQ \geq 1 \qquad \text{indicated high risk}$$
$$0.1 < RQ < 1 \qquad \text{indicated moderate risk}$$
$$RQ \leq 0.1 \qquad \text{indicated low to no risk}$$

Contaminant-specific RQs greater than 0.1 should be interpreted as cause for concern. This criterion allows for some degree of conservatism in the risk analysis, and is established to take errors in sampling and measurement into account. Thus, the RQs generated and interpreted below might well be thought of as worst-case estimates.

These calculations were conducted in two ways. The first assumed the harbor stations to be statistical replicates of Allen Harbor conditions, so that the appropriate statistic for consideration is the mean RQ. This approach reflects the uncertainties of the entire measurement and assessment process. The second considered risk to be best indicated by maximum exposure conditions in the harbor, making no assumptions about contaminant transport mechanisms within the system. This approach undoubtedly yields a more conservative analysis of ecological risk.

Quotients calculated for Allen Harbor sediments are given in table 29. These ranged in magnitude from much less than 0.1 to as high as 47 for the maximum level observed of the pesticide DDT. While useful in identifying particular contaminants of ecological concern, such a presentation may not adequately convey the overall level of risk for Allen Harbor. To view them in a different manner, quotients are summarized by magnitude in figures 46–49. Classes of contaminants are identified in these figures as falling into the three levels of risk delineated above.

Table 27. Toxicological benchmark concentrations for sediments.

Contaminant	Effect Range-Low	Benthic Community Composition AET
p,p'-dichlorodiphenyl dichloroethene (DDE)	2	9
p,p'-dichlorodiphenyl dichloroethane (DDD)	2	16
p,p'-dichlorodiphenyl trichloroethene (DDT)	1	34
a-chlordane	0.5	na [b]
PCB	50	1,000
fluorene	35	1,000
phenanthrene	225	5,400
anthracene	85	4,400
fluoranthene	600	24,000
pyrene	350	16,000
benz[a]anthracene	230	3,600
chrysene	400	9,200
benzo[a]pyrene	400	3,600
dibenz[a,h]anthracene	60	970
copper	70	530
zinc	120	410
chromium	80	260
lead	35	450
nickel	30	>140
cadmium	5	5.1
silver	1	>6.1
mercury	0.15	2.1
arsenic	33	57

[a] Concentrations reported in ppb dry weight for organic contaminants, ppm dry weight for metals.

[b] na = not available.

Table 28. Toxicological benchmark concentrations for marine waters.

Contaminant	EPA Marine Chronic Criterion
p,p'-dichlorodiphenyl trichloroethene (DDT)	0.001[a]
PCB	0.03
fluoranthene	16[b]
benzene	700
tetrachloroethane	450
toluene	5,000

[a] All concentrations reported in ppb.

[b] Concentration represents lowest observed effect level.
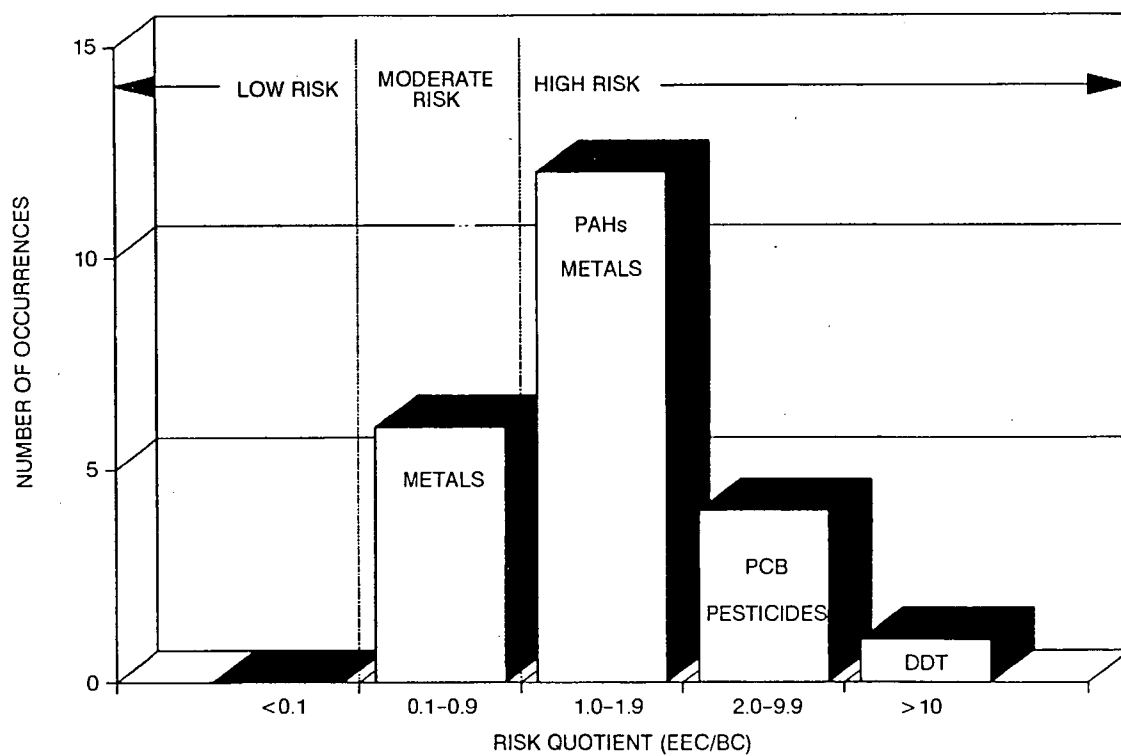
Figure 46. Sediment risk quotients based on ER-Ls and mean contaminant concentrations.
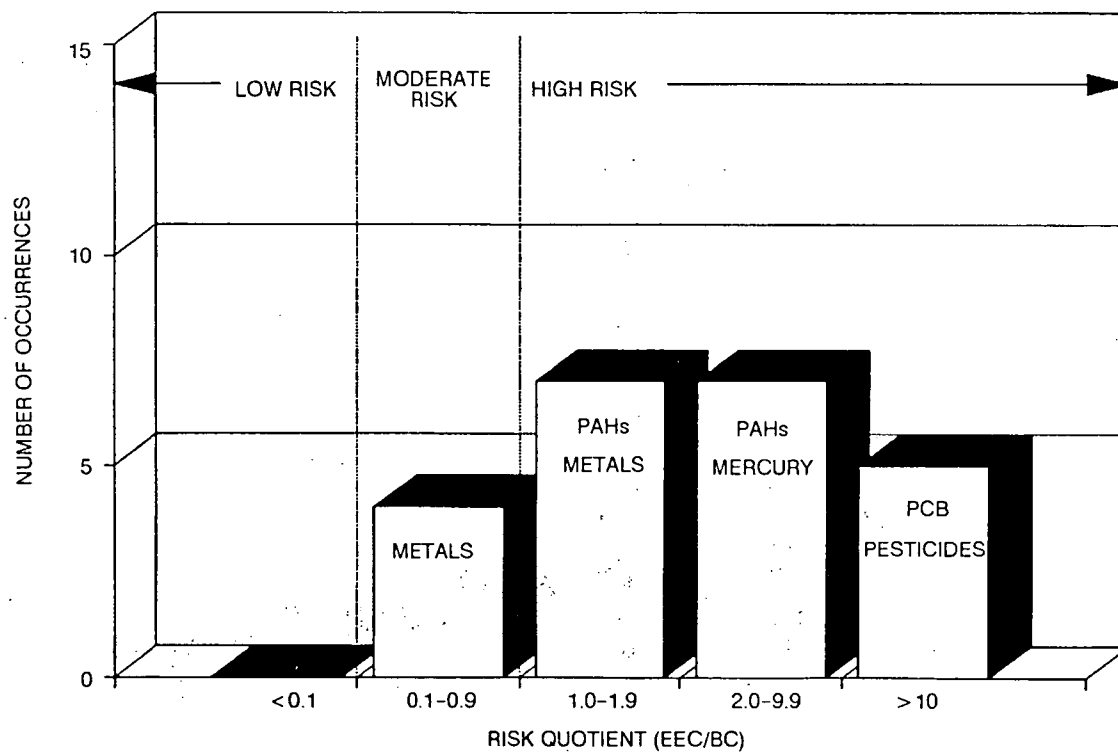
Figure 47. Sediment risk quotients based on ER-Ls and maximum contaminant concentrations.

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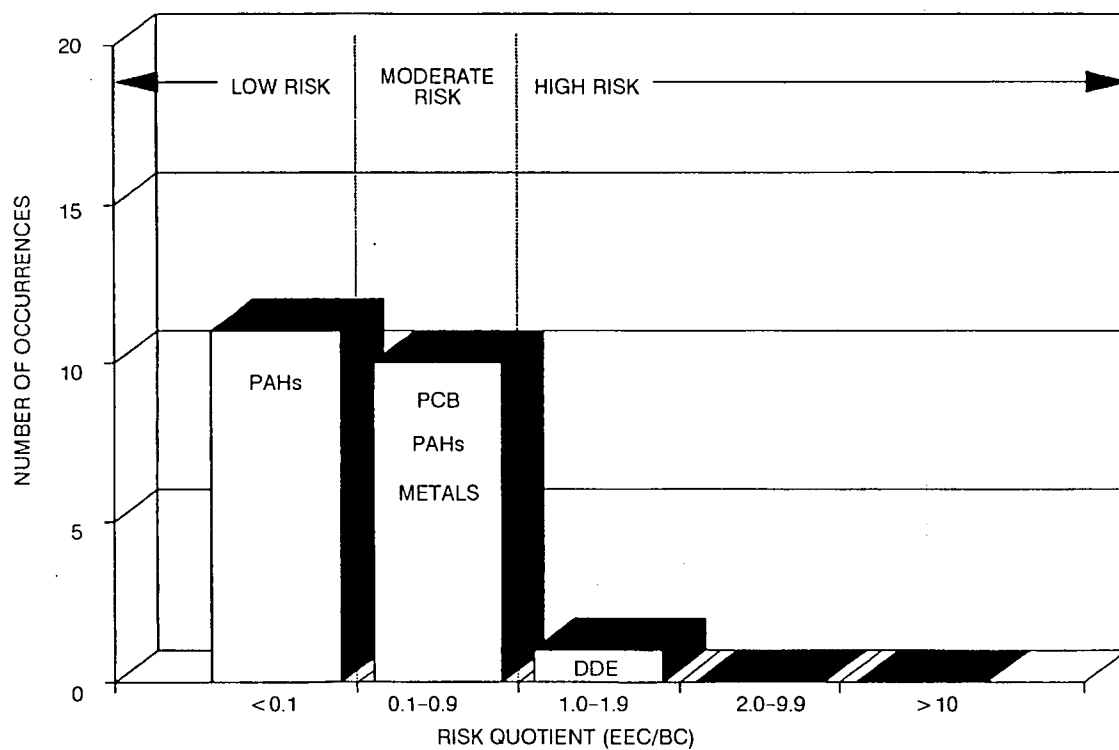
Figure 48. Sediment risk quotients based on AETs and mean contaminant concentrations.
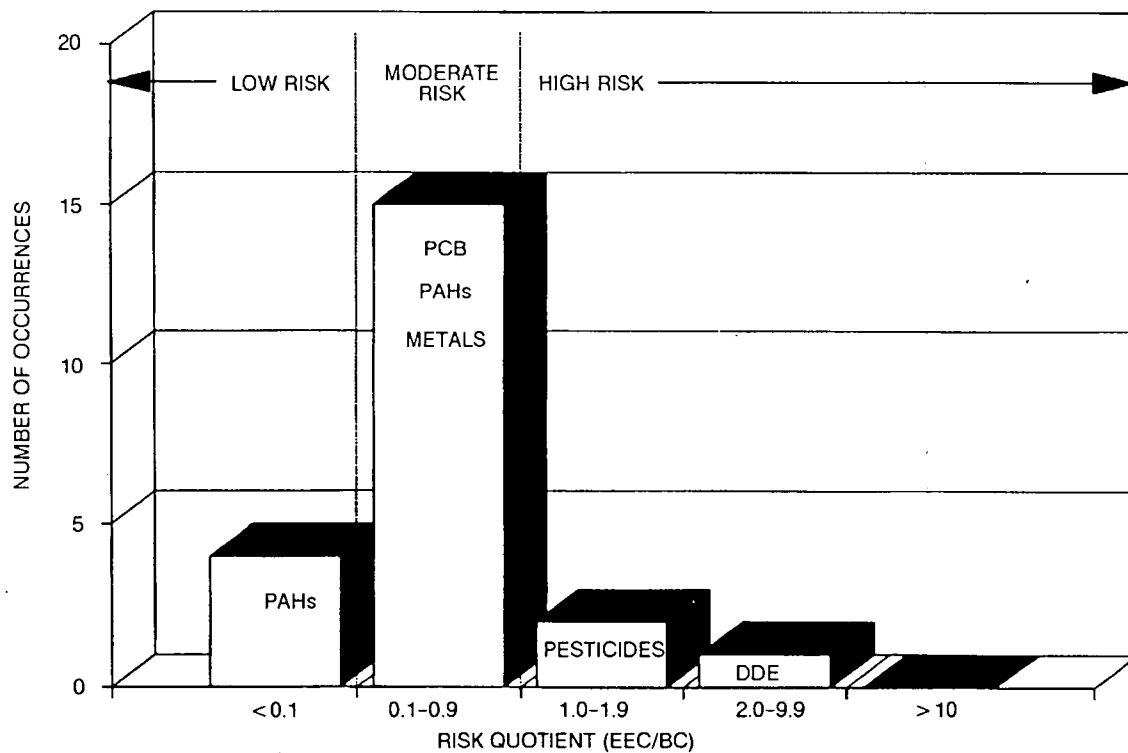
Figure 49. Sediment risk quotients based on AETs and maximum contaminant concentrations.

Table 29. Risk Quotients calculated for contaminants in Allen Harbor sediments.

Contaminant	Effect Range-Low		Benthic Community Composition AET	
	Mean RQ	Maximum RQ	Mean RQ	Maximum RQ
p,p'-dichlorodiphenyl dichloroethene (DDE)	7.6	18.8	1.7	4.2
p,p'-dichlorodiphenyl dichloroethane (DDD)	3.7	11.7	0.5	1.5
p,p'-dichlorodiphenyl trichloroethene (DDT)	11.5	47.4	0.4	1.5
a-chlordane	4.6	14.7	na*	na
PCB	6.4	10.1	0.3	0.5
fluorene	0.7	1.4	<0.1	<0.1
phenanthrene	1.4	3.6	<0.1	0.1
anthracene	1.1	3.1	<0.1	<0.1
fluoranthene	1.1	2.5	<0.1	<0.1
pyrene	1.9	4.8	<0.1	0.1
benz[a]anthracene	1.0	1.9	<0.1	1.2
chrysene	1.0	2.0	<0.1	<0.1
benzo[a]pyrene	0.7	1.6	<0.1	0.2
dibenz[a,h]anthracene	1.4	3.1	<0.1	0.2
copper	1.3	1.8	0.2	0.2
zinc	1.3	1.6	0.4	0.5
chromium	0.6	0.8	0.2	0.7
lead	1.6	1.9	0.1	0.4
nickel	0.7	0.8	<0.1	<0.2
cadmium	0.2	0.3	0.2	0.2
silver	1.0	1.4	<0.2	0.2
mercury	1.0	3.2	<0.1	0.2
arsenic	0.2	0.3	0.1	0.1

*na = not available.

The conclusions which can be drawn from this analysis depend upon which BCs are incorporated in the quotient calculation. Factors mitigating the responses of ecological systems to particular contaminants are not accounted for in the more conservative ER-Ls, and numerous instances exist in which natural communities are exposed to the identified levels of contaminants and yet show no negative response. By their very definition, AETs (figures 48 and 49) are most likely the better benchmarks against which to assess environmental contamination.

An interpretation of these figures also depends upon which EECs are involved. Risk quotients based only on maximum contaminant concentrations do not reflect spatial variation in sediment pollution, and probably unduly bias assessment of overall risk

towards that associated with localized "hot spots." An appreciation of harbor-wide risk is better gained by using mean EECs.

Accepting these arguments, our interpretation is that Allen Harbor sediments pose a moderate degree of risk to benthic communities. This risk derives primarily from pesticides, PCBs, and selected metals and PAHs. There is, however, no clear association of this risk with the land-based hazardous waste sites located at NCBC Davisville.

Based upon the small number of RQs calculated for Allen Harbor surface waters, the ecological risks associated with waterborne contaminants appear to be minimal (figure 50). This contrasts with the *Mytilus* SFG results presented earlier. It may be that contaminants for which BCs do not exist, or which were not quantified in this study, are playing some role in reducing harbor water quality.

ALLEN HARBOR IN A LARGER CONTEXT

Perhaps a more subjective but equally useful approach to assessing ecological risks associated with the landfill and Calf Pasture Point is to compare the results of all assessment activities in Allen Harbor with those obtained for the bay stations. At a gross level, differences observed in such a comparison might reasonably be attributed to the unique association of Allen Harbor with the hazardous waste sites. Confounding this assessment are the other unique attributes of the harbor, such as its enclosed nature, and the high level of boating activity present therein.

Information obtained from Phase I activities about the status of Allen Harbor relative to Narragansett Bay is summarized in figure 51. Symbols in that figure correspond to the relative magnitude of negative effects suggested by the results of each assessment activity. Thus, double pluses denote a relatively large potential of risk, single pluses correspond with a moderate indication of risk, and minuses indicate little or no risk. To some extent, these designations incorporate professional judgment based on experience with these assessment tools in other environmental settings. They are intended to be viewed in a qualitative fashion only.

At this level of analysis, there is a fairly strong indication that both sediment and water quality are affected in Allen Harbor relative to the bay proper. However, other sites within the bay also appear to be affected to some degree. The causes of these suggested risks are not at all clear, since none of the sites exhibit untoward contamination. One clear conclusion is that Allen Harbor appears to be no more affected than a typical East Coast embayment.
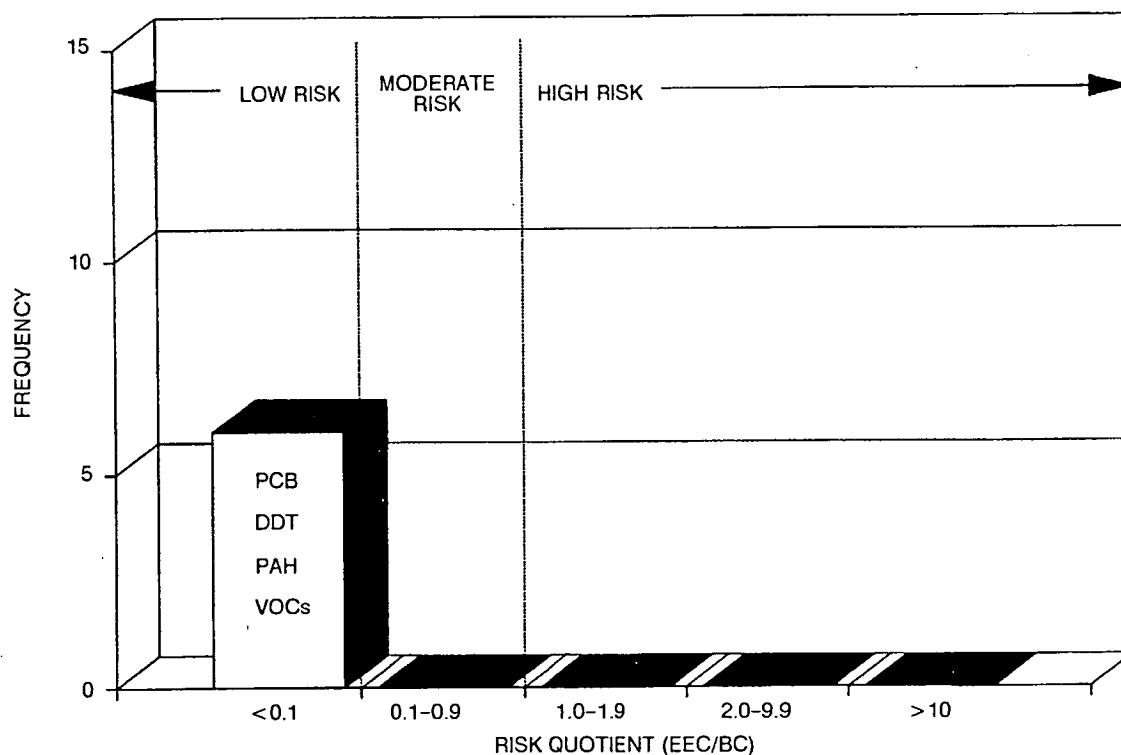
Figure 50. Water-column risk quotients based on Chronic Water Quality Criteria.

ALLEN HARBOR VERSUS NARRAGANSETT BAY

	SUBTIDAL							INTERTIDAL		
	AH	TTN	MV	NJ	PC	GB	ERLN	AH	CC	MP
AMPHIPOD TOXICITY	−	−	−	−	−	−		−	−	−
SCE	+		+							
METABOLIC COOPERATION	−		−							
SEA URCHIN FERTILIZATION	+ +		+							
DEVELOPMENT	+ +		+							
QUAHOG CONDITION	+	−	−	−	−	−				
MYTILUS SFG	+ +	+	−				−			
PHAGOCYTIC INDEX	−						−			
PATHOLOGY	−		−	−	−	−		+ +	−	+ +
COLIFORMS	+ +									
PCBs	+		+	−	+	−		−	−	−
PAHs	−		−	−	−	−		−	+	−
PESTICIDES	−		−	−	−	−		−	−	−
STEROLS	−		−	−	−	−		−		
VOCs	−		−							
METALS	−		−	−	−	−		−	−	−
BUTYLTINS	−		−		·			+ +	−	−

Figure 51. Overview of Phase I effect and exposure assessments.

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CONCLUSIONS

Results obtained during Phase I suggest no major environmental problems unique to Allen Harbor, but do call into question some aspects of the quality of water column and sediment conditions. Most notably, mussels deployed in the harbor consistently exhibited reduced physiological condition relative to those exposed at other stations in Narragansett Bay. The causes of this reduction remain unclear; neither chemical, histological, nor immunological analysis provided clues as to the source or mechanism of this effect.

Although sediments were not toxic to *Ampelisca*, a sensitive and commonly used benthic test species, effects were observed on sea urchin early life stage processes and in biomarkers assays. The interpretation of these results in a risk framework is not straightforward. Although the relationship between the toxicity of extracted and fractionated constituents of sediments and ecological effects is not at all clear, exposure to interstitial water is certainly a commonplace phenomenon in benthic communities. The meaning of the observed responses is further confounded by the general lack of effects observed at higher levels of biological organization: *in situ* populations of benthic organisms seemed reasonably healthy with respect to those in other areas of the Bay. REMOTS survey data support this observation.

The increased incidence of hematopoietic neoplasia is problematic with respect to this general observation. Although its etiology is not fully understood, infective agents have been suspected in its formation. The pollution of sediments (or water column) may also be important, at least in increasing susceptibility to infection or in exacerbating existing conditions. The problem is clearly not unique to Allen Harbor, as data from this and other studies suggest similar problems elsewhere in Narragansett Bay and the eastern U.S. The question of whether Allen Harbor is acting as a locus of neoplastic disease will be investigated further in Phase II of this project.

The initial steps in the quantification of environmental risks involved a description of the waste sites potentially affecting the harbor and the contaminant exposure fields associated with those sites. Although not conducted to a sufficient extent, analyses of the landfill and the magnitude of contaminant migration from it into Allen Harbor suggest localized effects above existing conditions, especially since elevated contaminant levels were observed. Changes in ground water movement or susceptibility of contaminant release (e.g., storage drum breakage) represent a real, albeit unquantified, risk to Allen Harbor. The contribution of the landfill to current environmental problems within the harbor, as well as those of boating activity and runoff from the surrounding land mass, will be examined more closely in Phases II and III.

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SUMMARY

In 1988, the Environmental Protection Agency's (EPA) Environmental Research Laboratory at Narragansett (ERLN), Rhode Island, and the Naval Ocean Systems Center (NOSC), entered into a Memorandum of Agreement (MOA) to develop cooperative research and monitoring activities for conducting marine and estuarine ecological risk assessments. Under this agreement, case studies were developed to characterize the risk of Navy hazardous waste disposal sites that could affect aquatic ecosystems. This joint research supports the Navy's response to the requirements of the Comprehensive Environmental Response Compensation and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendment and Reauthorization Act of 1986 (SARA). Additionally, case studies under the agreement enabled ERLN and NOSC to develop and refine methods for examining ecological risks associated with anthropogenic wastes in the marine environment.

The first case study developed under the MOA was the Risk Assessment Pilot Study (RAPS), conducted at the Naval Construction Battalion Center (NCBC), Davisville, Rhode Island. NCBC Davisville is located on Narragansett Bay, directly adjacent to a small embayment known as Allen Harbor. In 1984, Allen Harbor was closed to shellfishing by the Rhode Island Department of Environmental Management due to concern of contamination from disposal sites located at NCBC Davisville. Two sites at NCBC Davisville were of particular concern with respect to potential negative impacts on Narragansett Bay. These are a 15-acre landfill next to Allen Harbor and Calf Pasture Point, which separates Allen Harbor from the West Passage of Narragansett Bay. The landfill had been used for disposal for a variety of wastes, including solvents, polychlorinated biphenyl (PCB)-contaminated oils, preservatives, sewage sludge, chromic acid, and construction rubble from 1946 to 1972. Calf Pasture Point was used for disposal of calcium hypochlorite, chloride, and decontaminating solutions during 1960 to 1974 in a cement-lined pit. Contaminant transport from these two sites posed a potential risk to the ecological systems of Allen Harbor and Narragansett Bay. NCBC Davisville was added to the National Priorities List in November 1989.

A phased approach was developed to provide information regarding the ecological risks posed by these hazardous waste sites to Allen Harbor and Narragansett Bay. Phase I involved the collection and collation of environmental data characterizing the ecology, natural resources, sediment, and water quality of Allen Harbor relative to Narragansett Bay. This information was used to develop a preliminary ecological risk assessment of the harbor. Based on the findings of Phase I, activities in Phase II will be identified to either verify the lack of adverse ecological impact (Option I) or determine the nature and extent of contaminant impact on the marine system (Option II). If Option I is indicated, studies are to be conducted to confirm the lack of negative impact. Phase III was designed to evaluate the effectiveness of remedial activities,

should these be required, and to examine the long-term risks of these sites to the marine environment. In addition to development of a final marine ecological risk assessment for NCBC Davisville, a monitoring program for continuous verification of environmental safety would be identified and implemented in Phase III. The approach taken to address the objectives of Phase I and the results of those activities are the subject of this report.

The technical approach taken in Phase I involved applying a variant of the ecological risk assessment strategy developed by ERLN. This included collecting information about the physical and chemical attributes of the waste material (waste site characterization); the distribution of contaminants within Allen Harbor (exposure assessment); and the effects of these contaminants on ecological systems within the harbor (effects assessment). Because the waste material had been in place for some time, the emphasis of both exposure and effects assessments was on *a posteriori* quantification of impacts that have (or have not) occurred. Thus, the majority of activity within these steps were field-oriented and empirical in nature.

The waste site characterization portion of the study centered primarily on identifying chemicals emanating from the disposal sites. Samples of water flowing from seeps on the face of the landfill, and of the sediments surrounding these seeps, were obtained for chemical analysis. With TRC Environmental Consultants, Inc. (TRC-ECI) as the on-site contractor for the Remedial Investigation/Feasibility Study (RI/FS), samples of ground water from test wells and a single test pit were also obtained for analysis, as well as for quality assurance intercalibrations. Additionally, the earlier site investigation (SI) provided general descriptions of the material disposed at the sites. This information was used to identify the range and quantities of environmental contaminants which might be transported into the harbor and nearby Narragansett Bay.

There were 29 permanent stations, 23 subtidal and 6 intertidal, established in Allen Harbor (AH) and at several locations in Narragansett Bay for assessment of both exposure and effects. The Allen Harbor stations included 11 subtidal stations (denoted AH1–AH11), and 3 intertidal stations (AH12–AH14). A fourth intertidal station was located on the south shore of Calf Pasture Point (FDA). Seven additional subtidal stations (TTN1–TTN7) were situated along a T-shaped transect originating at the mouth of the harbor. These stations could be used to detect transport of contaminants from Allen Harbor to Narragansett Bay proper. Four of the remaining five subtidal stations were located mid-bay at the mouth of Greenwich Bay (GB), immediately north of Conanicut Island at a historically visited site called North Jamestown (NJ), directly off Mount View in the middle of the West Passage of the bay (MV), and on the east side of Prudence Island (PI) in Potter Cove (PC). The fifth and sixth intertidal stations were situated mid-bay at Marsh Point (MP) and on the west side of Prudence Island in Coggeshall Cove (CC, more appropriately Sheep Pen Cove). The position of these stations

at mid-bay minimized any influences of north to south gradients in hydrographic parameters and water quality on comparison among stations. While Allen Harbor is also located mid-bay, comparison of data from these stations with that obtained for Allen Harbor yielded information concerning the status of the harbor relative to the rest of Narragansett Bay. A final subtidal station (LAB) was located off the ERLN dock in the southern part of the bay to serve as a lower bay reference.

Using information obtained as part of the waste site characterization, the spatial distributions of specific contaminants of concern were quantified through extensive field sampling efforts. Because fine-grained sediments typically act as reservoirs of anthropogenic contaminants, and therefore serve as integrators of contaminant flux through the system, sampling efforts focused on intertidal and subtidal sediments in Allen Harbor for detailed chemical and physical analyses. Additionally, several stations in the West Passage of Narragansett Bay were sampled to address questions of contaminant movement and to provide reference comparisons. Although much more dynamic and often misleading with respect to contaminant concentration and movement, water-column samples were also obtained inside and outside the Harbor for chemical and bacteriological analyses. Tissue residues of contaminants in several resident biota were quantified to provide information regarding the levels of exposure actually experienced by organisms. Native bivalves, including the quahog, *Mercenaria mercenaria*, the soft-shell clam, *Mya arenaria*, the oyster, *Crassostrea virginica*, and an infaunal polychaete, *Nephtys incisa*, were obtained both within and outside of Allen Harbor for comparative purposes. These organisms display a range of ecological lifestyles, and are important ecological and commercial resources in Allen Harbor and Narragansett Bay.

The ecological impacts of contaminants within Allen Harbor were evaluated through a combination of field sampling, field experimentation, and laboratory assays. These activities involved evaluation of a number of biological endpoints shown to be sensitive to contaminant insult and whose relationship with ecological well-being are fairly well established. Native *Mercenaria mercenaria*, *Mya arenaria*, and *Crassostrea virginica* were sampled for population abundance, individual condition, and histopathological effects. Collections again were obtained both inside and outside Allen Harbor for comparative purposes. The blue mussel, *Mytilus edulis*, was deployed at several stations to address the effects of water quality on physiological condition and growth. Finally, the toxicity of sediments within Allen Harbor and at stations in Narragansett Bay was determined in the laboratory using both standard amphipod (*Ampelisca abdita*) bioassays and biomarker tests under development at ERLN. These latter tests use field exposed organisms or laboratory exposed cell cultures to investigate the modes and mechanisms of contaminant impact on cellular and subcellular biological processes.

Information collected during the waste site characterization, and exposure and effects assessments were synthesized into a preliminary assessment of ecological risk to Allen Harbor. Two approaches were used to characterize risk. The first involved calculation of risk quotients as the ratio of contaminant-specific exposure concentrations to effects benchmark concentrations for single contaminants. In this process, field measurements of sediment and water column contaminant concentrations were compared with published measures of sediment and water quality. The second approach compared the results of all biological and chemical assessments conducted for Allen Harbor with those obtained for stations in Narragansett Bay proper. The intent behind this latter approach was to evaluate conditions in Allen Harbor within the context of the larger bay system as a whole. Such an evaluation might identify potential influences of the land-based hazardous waste sites on the ecology of Allen Harbor.

The results these characterization and assessment activities are presented below.

WASTE SITE CHARACTERIZATION

Historic information indicated a range of waste materials to have been disposed in the Allen Harbor landfill, including complex organic and inorganic wastes such as jet fuel, waste oils, and coal ash, as well as organic solvents, asbestos, and sewage sludge. Exact quantities of the wastes disposed are unknown, although in some cases they may have been substantial. Chemical analysis of seep, test pit, and well water samples provided a more direct characterization of wastes potentially impacting the harbor. Samples obtained from the south side of the landfill contained high levels of several chlorinated solvents, including cis- and trans-1,2-dichloroethene and 1,2-dichloroethane. Methyl-t-butyl ether, toluene, acetone, and methylene chloride were commonly encountered at low levels. In addition to these compounds, analyses also suggested the presence in selected seeps of aromatic hydrocarbons derived from petroleum products such as fuel oil, diesel oil, gasoline, or kerosene.

Very high levels of total PCBs were measured in seep samples from the south face of the landfill. The maximum value observed of 1.49 ppb exceeded U.S. EPA's marine water quality criterion (WQC) concentration of 0.030 ppb for PCBs, although the method of sample collection may have confounded seep water analysis due to the inclusion of particulate material.

Comparison of ionic concentrations in seep samples with an open ocean seawater standard indicated these waters to be approximately 50–80 percent seawater. This result suggests that Allen Harbor seawater infiltrates the porous sediments and soils of the landfill on flood tides, and drains from the landfill on the following ebb tides. Despite this, trace metal concentrations observed in seep samples were very high, violating the WQC for copper (Cu), cadmium (Cd), and lead (Pb). Although no metals

data are available for ground water samples for comparison, these data are probably more indicative of sediment chemistry than of seep water chemistry.

Perched and ground water samples collected in conjunction with TRC-ECI from a single test pit and four wells contained a suite of volatile organic compounds (VOCs) which differed in some respects from that observed in seep samples. Although elevations in cis-1,2-dichloroethane were recorded, trans-1,2-dichloroethene and 1,2-dichloroethane were generally absent. High levels of chlorobenzene and benzene were present, however. Petroleum hydrocarbons were also present (up to 100–200 ppb) in some samples. Total PCB and polycyclic aromatic hydrocarbon (PAH) concentrations were lower in ground water samples than in seep water, although PCB levels were still in violation of WQC. Pesticides were typically not detected in the ground water.

EXPOSURE ASSESSMENT

Sediment Exposure Conditions

Large variations in composition were observed in the proportions of sand, silt, and clay among subtidal stations. While AH, MV, and PC sediments consisted primarily of clays and silts, GB sediments were greater than 90 percent sands. NJ sediments were also largely sands. These patterns reflect the depositional and erosional characteristics of each site, which may have affected the chemical and biological attributes of each. In contrast to subtidal sediments, sediments collected from intertidal stations were fairly similar with respect to grain size distribution. Sand predominated these samples in all cases, perhaps reflecting similarity in the physical processes acting in these areas.

Chemical analyses revealed no differences between Allen Harbor and Narragansett Bay stations in pesticide, PCB, or butyltin concentration. However, differences were found among stations in all inorganic contaminants measured, as well as in sterols and PAHs. When significant differences among stations were observed, Allen Harbor often fell within the group of stations displaying the highest levels. Generally, however, the highest concentrations of contaminants were measured at PC. Allen Harbor chemistry was most similar to that of Mount View, while NJ and GB were least contaminated. Only the pesticide hexachlorobenzene (HCB) was statistically highest in Allen Harbor. In no instance were contaminant levels in Allen Harbor significantly lower than those at all other stations.

The importance of grain size was limited primarily to inorganic compound concentrations. Despite the removal of the influence of grain size through Analysis of Covariance (ANCOVA), trace metal levels typically remained the highest in PC sediments. This material was skewed towards small particle sizes, with a relatively low percentage of sand.

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These results indicate elevations of selected contaminants (PAHs, HCB) in Allen Harbor relative to other areas of mid-Narragansett Bay. However, concentrations at all stations, including Allen Harbor, were generally low in comparison with other estuarine sediments in the northeast U.S. Although there was no difference in butyltin concentrations between the Allen Harbor and Mount View sites (the only subtidal sediments analyzed for butyltin), their levels were comparable to those measured in more heavily utilized harbors around the U.S.

Within Allen Harbor proper, subtidal sediment from station AH5 at the center of the harbor typically contained lower contaminant concentrations than those elsewhere within the harbor. Conversely, station AH8 at the southern end of the harbor usually contained the highest levels. Of the 52 contaminants measured in this study, only 8 (15 percent) had their highest levels near the landfill (10 compounds (20 percent) would be expected to be highest at that station based on random chance alone). These 8 include manganese (Mn), alpha- and gamma-chlordane, DDD, DDT, anthracene, and the two benzotriazoles. Thus, little evidence of contaminant migration from the landfill was observed. Similarly, the two stations closest to Calf Pasture Point (AH3 and AH10) displayed no elevations in contaminants reported disposed at that site. The broad chemical patterns observed within Allen Harbor subtidal sediments were unrelated to grain size distribution, although the number of samples involved in these analyses was not sufficient to detect subtle relationships.

No statistically significant differences in intertidal contaminant level were observed between Allen Harbor and Marsh Point, the only sites receiving replicate analytical effort. However, large variation existed in concentration among all stations. For instance, mean Pb and Cu levels were an order of magnitude higher in Allen Harbor than at CC, MP, or FDA. Conversely, benzo[a]pyrene (B(a)P) concentrations at CC were nearly 20 times those in Allen Harbor, and over 30 times those observed at FDA. Total PAH levels differed in a similar fashion. The causes of this variation are not clear.

Differences were also indicated between intertidal pollutant levels and those seen in subtidal sediments. Intertidal PCB concentrations in Allen Harbor were roughly a factor of 40 lower than their subtidal counterparts. This may reflect losses due to volatilization or aerobic microbial degradation. Mean concentrations of the majority of metals were within a factor of 2 between intertidal and subtidal sediments, with no consistent trends between the two matrices. Sterol and butyltin concentrations were lower intertidally than those seen in the subtidal sediments.

Within Allen Harbor, intertidal contaminant levels were typically lowest at the south end of the landfill (AH13). Concentrations at AH12, north of the landfill, and AH14, east of Calf Pasture Point, were similar except in the case of metals. Levels of chromium (Cr), arsenic (As), Pb, and Cu were 4 to 20 times higher at AH14. Because

such elevations may reflect contaminant migration into Allen Harbor from waste disposal sites on Calf Pasture Point, this sample has been targeted for reanalysis to ascertain the validity of the levels quantified.

Tissue residue levels in benthic organisms provided an additional measure of exposure. Significant differences were often observed among stations in quahog (*Mercenaria mercenaria*) tissue residues, although few patterns were discernible with respect to contaminant class. Unlike the results obtained for subtidal sediments, no station consistently exhibited the highest levels of contaminants. Allen Harbor grouped with stations exhibiting the highest mean concentration for approximately 40 percent of the contaminants, but was significantly elevated above all other stations for iron (Fe) only. This metal is unimportant toxicologically at the levels observed here. Allen Harbor quahogs also contained higher tributyltin (TBT) levels (approximately two times) than those from Mount View, the only other station where this compound was quantified. Interestingly, levels of Cr and As were lowest in AH animals.

Concentrations of PCB and PAH compounds measured in this study are comparable to levels reported in quahogs from upper and mid-Narragansett Bay, and trace metal levels were similar to those reported for another infaunal filter feeding bivalve, *Pitar morrhuana*, at a site just south of Allen Harbor. Positive correlations were observed only between a small subset of quahog tissue residues (Cu, Pb, and Fe) and contaminant concentrations in subtidal sediments. Because *Mercenaria* is a water column filter feeder, the small number of significant relationships is not particularly surprising. Stronger dependence of bioaccumulation on sediment chemistry might be expected in examinations of deposit-feeding organisms.

In subtidal chemistry levels, tissue residues of quahogs within Allen Harbor were typically highest at station AH8, at the southern end of the harbor. Unlike the sediment data, however, residues at AH5 were not particularly low relative to other Allen Harbor stations. Of 49 contaminants measured in quahogs, only 4 (8 percent) were highest near the landfill at station AH2; 10 would be expected by chance alone.

Bioaccumulation by *Mya arenaria* was also examined. Few instances of differences in contaminant concentration were observed among stations, which were limited to the pesticides g-BHC and a-chlordane, and to DBT and TBT. For all but a-chlordane, Allen Harbor *Mya* contained the highest levels of any station. Tissue residues of Cu and PAHs observed in Allen Harbor were somewhat elevated with respect to those reported for *Mya* from Quincy Bay, MA. PCB levels, on the other hand, were several times lower in Allen Harbor animals. TBT residues were extremely high (8,800 ppb dry weight) in Allen Harbor *Mya*. In comparison, Allen Harbor quahog TBT residues were 8 times lower, reflecting a trend opposite of that seen in intertidal and subtidal sediments. No relationships between other contaminant tissue residues and sediment contamination were observed.

Contaminant residues were generally higher at AH12 than at other stations within Allen Harbor. Of the 43 compounds quantified in soft shell clams, 20 (47 percent) were highest at this station. These consisted primarily of trace metals and PAHs, differing somewhat from the pattern seen in intertidal sediments. Samples collected for AH14 did not show the disproportionately high levels of metals observed in the intertidal sediment. Residues were again generally lowest in clams from AH13.

Residue analyses of the indigenous polychaete *Nephtys incisa* were restricted to inductively coupled plasma spectrometer (ICP) trace metals due to the lack of sufficient quantities of polychaete tissue. Observed levels of Cu, zinc (Zn), Cr, and Mn were statistically indistinguishable between Allen Harbor and Mount View worms. For the remaining four metals, Pb, nickel (Ni), Cd, and Mn, residues in MV worms were significantly higher than those in Allen Harbor worms. With the exception of chromium and lead, residues in Allen Harbor polychaetes were similar to those reported for Long Island Sound *Nephtys*; chromium concentrations were substantially lower in AH, while lead residues were an order of magnitude greater in AH worms. Interestingly, MV polychaetes contained Pb levels even greater than those from the harbor.

Water-Column Exposure Conditions

Large volume water samples from Allen Harbor and Mount View were analyzed for organic compounds only. Concentrations of pesticides in both dissolved and particulate phases were generally below detection. PCBs were observed in the particulate phase at concentrations in the 1-2 pptr range, with somewhat higher levels in Allen Harbor. No PCBs were detected in the dissolved phase at either station. Generally, contaminant levels were similar to background levels observed in relatively clean areas.

Tissue residues of selected bivalves were also examined to assess water column exposure conditions. Overall, significant differences in deployed *Mytilus edulis* residues were found among stations for seven analytes: HCB, Cu, Cd, silver (Ag), total PAHs, monobutyltin (MBT), and TBT. Residues of mussels deployed in Allen Harbor fell within the group of stations exhibiting the highest means six of those seven times, but never exhibited the statistically highest level. Contaminants measured at a station located outside the mouth to Allen Harbor were statistically indistinguishable from those of Allen Harbor animals. Residues in LAB mussels were generally lowest among stations.

Residues quantified in Allen Harbor tissues were fairly typical of clean areas in the northeast, although PCB and total PAH concentrations were somewhat higher than those reported for some areas. For instance, levels of Cu, Cd, and Pb fell within or below the ranges observed in Lower Narragansett Bay and Central Long Island Sound, but PCB residues were higher than those reported for Lower Narragansett Bay, Block

Island Sound, and Central Long Island Sound. Butyltin levels in Allen Harbor mussels are in general agreement with those reported throughout the east coast. When compared to the reported levels of butyltins from mussels in nearby areas, however, residues of all three tin species are elevated in the present study by factors of 2–20 or more.

Tissue residues measured in *Crassostrea virginica* collected from AH and PI exhibited significantly higher levels in Allen Harbor for 11 contaminants, including total PCB, total PAHs, and several pesticides. Allen Harbor residues were also elevated with respect to those observed in oysters in other areas of the northeast coast. No patterns in oyster tissue residues were observed across the face of the landfill.

EFFECTS ASSESSMENT

Status of Indigenous Organisms

Mercenaria in Allen Harbor were significantly smaller than those found at all stations but PC. Despite the closure of Allen Harbor to shell fishing in 1984, mean shell length was some 2–3 cm shorter than those of animals collected from Mount View, Greenwich Bay, and North Jamestown. Reduced shell size may reflect some impact of sediment or water quality, or may simply be the result of a lack of sufficient time for substantial individual growth following the heavy fishing pressure by Allen Harbor quahogs prior to harbor closure. Condition index followed a pattern among stations similar to that of shell length. Proximity to the landfill had no discernible effect on length or condition of *Mercenaria*. Samples collected nearest the landfill (AH1 and AH2) exhibited among the highest means of all AH stations. Perhaps reflecting aspects of sediment chemistry, quahog shell length was lowest and condition index second lowest at station AH8 at the south end of the harbor. Generally, no significant pathologies were observed in Allen Harbor animals.

Densities of *Mya* were higher in Allen Harbor than at Marsh Point or Coggeshall Cove. This pattern likely reflects the intensity of recreational clamming directed towards each area. Unlike that displayed by quahogs, no clear pattern in *Mya* shell length emerged in station-wise comparisons, although Allen Harbor animals were typically larger than those from MP and CC. No discernible trends in shell length were evident across stations within the harbor. On the average, Allen Harbor clams were more robust than those from other sites in autumn, but were the least robust in spring. As with quahogs, proximity to the landfill had little apparent effect on Allen Harbor *Mya* shell length or condition.

A number of pathological conditions were observed in *Mya arenaria* from all stations throughout this study. These included pathologies commonly associated with soft

shell clams, such as atypical cell hyperplasia in the gills and kidney, and inflammatory responses. The prevalence of kidney concretions, parasitism, and mycoplasma infection varied seasonally across sampling periods, but generally occurred at all sites within a given sampling period. Neoplastic lesions associated with the heart and hematopoietic system (HN) were found in clams collected in AH, at FDA and MP, but not at CC. Within Allen Harbor proper, the highest prevalence was found at station AH13. The presence of HN within Allen Harbor was not unexpected, as HN has been reported in soft shell clams throughout the western shore of Narragansett Bay, with historically highest rates observed in Allen Harbor.

Crassostrea in Allen Harbor were both larger and in better condition than those at PI. Shell fishing pressure may likely explain these differences. Histological examination of *Crassostrea* collected in Allen Harbor and at PI revealed no pathology in either sample. All organisms were in good to excellent health.

Sediment Effects

No ecologically meaningful mortality to the benthic amphipod *Ampelisca abdita* was associated with sediments collected from Allen Harbor or Narragansett Bay stations. The eight stations tested within Allen Harbor exhibited uniformly low toxicity indicating little impact from the landfill or Calf Pasture Point. Similarly, the lack of toxicity associated with the TTN transect outside the harbor indicated no migration of toxic constituents from the harbor into Narragansett Bay. In contrast, significant mortality was associated with material collected from the north, middle, and south faces of the landfill. Extreme mortality of 81.1 percent and 76.7 percent resulted from exposure to sediments from the north and middle faces respectively. Although suggestive of landfill-associated contaminant effects, material from all three sites was composed primarily of very course-grained material, thereby confounding toxicological analyses through a grain size effect.

In the absence of enzyme activation, neither Allen Harbor nor Mount View sediments exhibited significant mutagenic effect as determined by sister chromatid exchange response. When activated, however, both sediments induced a significant response. Under these conditions, Allen Harbor extracts were the more mutagenic. No significant response was observed from either sediment in the V79/metabolic cooperation assay for the presence of tumor promoters.

Allen Harbor and Mount View whole sediment extracts affected *Arbacia* fertilization, growth (length), and survival equivalently. Significant differences were found between 0.2 percent concentrations of both AH and MV, and the control treatments. Significant decreases from control treatments were also observed in the length and survival of 48-hour pluteus larvae exposed to concentrations of 0.05 and 0.2 percent of MV extracts and at a 0.2 percent concentration of AH. Additionally, the 0.05 percent

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concentration of AH retarded growth of *Arbacia* larvae. In opposition to these results, Allen Harbor interstitial water was substantially more toxic to sea urchin fertilization, growth, and survival than was Mount View interstitial water. However, even at a concentration of 50 percent MV extract, significant decreases were detected in growth relative to seawater controls. No fertilization was detectable at AH extract concentrations greater than 12.5 percent.

Water-Column Effects

Mytilus edulis deployed in Allen Harbor in May–June showed both lower clearance rate and higher respiration rate than did mussels deployed at the Narragansett Bay stations. Assimilation efficiency was equivalent across stations. When integrated into the scope for growth (SFG) index, these rates indicated significantly reduced physiological condition for Allen Harbor mussels. The remaining stations did not differ with respect to SFG. Chemical analysis of the soft tissues of these animals were equivocal with respect to the causes of the observed differences in physiological response. Mussels exposed during a fall deployment in September–October also exhibited differences in clearance and respiration rates with respect to station. These differences translate into SFG estimates that were depressed at AH and TTN relative to that at LAB. The consistently low clearance rate and SFG integration observed in Allen Harbor mussels indicates a harbor water quality problem. No differences were observed in the *in vivo* immunological response of *Mytilus* deployed in Allen Harbor and at LAB, nor was pathology observed in animals deployed at any of the four sites.

PRELIMINARY ASSESSMENT OF ECOLOGICAL RISK

Risk quotients (RQ) calculated for Allen Harbor sediments ranged in magnitude from much less than 0.1, to as high as 47 for the maximum level observed of the pesticide dichlorodiphenyltrichloroethene (DDT). Classes of contaminants were identified as falling into three levels of concern: (1) those with quotients less than 0.1 (no risk presumed), (2) those with RQs greater than 0.1 but less than 1 (moderate risk presumed), (3) and those with RQs greater than 1 (risk presumed). Although the actual quotient values for specific contaminants varied with the particular ecological benchmark used, the major risk to benthic systems derives primarily from pesticides, PCBs, and selected metals and PAHs. There is, however, no clear association of this risk with the land-based hazardous waste sites located at NCBC Davisville.

Based upon the small number of RQs calculated for Allen Harbor surface waters, the ecological risks associated with water-borne contaminants appear to be minimal. This contrasts with the *Mytilus* SFG results presented earlier. It may be that contaminants for which toxicological benchmarks do not exist, or which were not quantified in this study, are playing some role in reducing harbor water quality.

Perhaps a more subjective, but equally useful approach to assessing ecological risks associated with the landfill and Calf Pasture Point is to compare the results of all assessment activities in Allen Harbor with those obtained for the bay stations. At a gross level, differences observed in such a comparison might reasonably be attributed to the unique association of Allen Harbor with the hazardous waste sites. Confounding this assessment are the other unique attributes of the harbor, such as its enclosed nature, and the presence of high-level boating activity.

At this level of analysis, there is a fairly strong indication that both sediment and water quality are impacted in Allen Harbor relative to the bay proper. However, other sites within the bay also appeared to be impacted to some degree. The causes of these suggested risks are not at all clear, as none of the sites exhibited untoward contamination. One clear conclusion that can be drawn is that Allen Harbor appears to be no more impacted than the typical East Coast embayment.

CONCLUDING REMARKS

Results obtained during Phase I suggest no major environmental problems unique to Allen Harbor, but do call into question some aspects of the quality of water column and sediment conditions. Most notably, mussels deployed in the harbor consistently exhibited reduced physiological condition relative to those exposed at other stations in Narragansett Bay. Impacts were observed on sea urchin early life-stage processes and in biomarkers assays, and an increased incidence of hematopoietic neoplasia in *Mya* was associated with proximity to Allen Harbor. Appreciation of the meaning of the observed responses within an ecological context is confounded by the general lack of impact observed at higher levels of biological organization: *in situ* populations of benthic organisms seemed reasonably healthy with respect to those in other areas of the bay.

The initial steps in the quantification of environmental risks involved description of the waste sites potentially impacting the harbor, and the preliminary description of contaminant exposure fields associated with those sites. Although not conducted to a sufficient extent, analyses of the landfill and the magnitude of contaminant migration from it into Allen Harbor suggest that localized impact above existing conditions might be possible in that elevated contaminant levels were observed. Changes in ground water movement or susceptibility of contaminant release (e.g., storage drum breakage) represent a real, albeit unquantified, risk to Allen Harbor. The contribution of the landfill to current environmental problems within the harbor, as well as those of boating activity and runoff from the surrounding land mass, are being examined more closely in Phase II.

REFERENCES

American Petroleum Institute. 1984. "Field and Laboratory Studies to Define the Occurrence of Neoplasia in the Soft-shell Clam, *Mya arenaria.*" API Publication No. 4345. American Petroleum Institute, Washington, DC.

Ames, B. N., J. McCann, and E. Yamasaki. 1975. "Methods for Detecting Carcinogens and Mutagens with the *Salmonella*/Mammalian-Microsome Mutagenicity Test." Mutation Research 31:347–364.

Barnthouse, L. W., G. W. Suter, S. M. Bartell, J. J. Beauchamp, R. H. Gardner, E. Linder, R. V. O'Neill, and A. E. Rosen. 1986. "User's Manual for Ecological Risk Assessment." Environmental Sciences Division Publication No. 2679. Oak Ridge National Laboratory, Oak Ridge, TN.

Bierman, V. J., Jr., J. H. Gentile, J. F. Paul, D. C. Miller, and W. A. Brungs. 1986. "Research Strategy for Ocean Disposal: Conceptual Strategy and Case Study." in *Environmental Hazard Assessment of Effluents* (H. L. Bergman, R. A. Kimerle, and A. W. Maki, eds.), Pergamon Press, New York, pp. 313–329.

Boothman, W. S., F. A. Osterman, and W. G. Nelson. 1989. "New Bedford Harbor Pilot Study Preoperational Monitoring Progress Report: Copper, Cadmium and Lead Concentrations in the Blue Mussel, *Mytilus edulis*, from the First and Second Preoperational Mussel Deployments." Progress report prepared for the U. S. Environmental Protection Agency, Region I. Environmental Research Laboratory, Narragansett, RI.

Breteler, R. J., K. J. Scott, and S. P. Shepherd. 1989. "Application of a New Sediment Toxicity Test Using the Marine Amphipod *Ampelisca abdita* to San Francisco Bay Sediments," in *Aquatic Toxicology and Hazard Assessment*, 12th Volume (U. M. Cowgill and L. R. Williams, eds.), ASTM STP 1027, American Society for Testing and Materials, Philadelphia, PA. pp. 304–314.

Brousseau, D. J. 1987. "Seasonal Aspects of Sarcomatous Neoplasia in *Mya arenaria* (Soft-Shell Clam) from Long Island Sound." *Journal Invertebrate Pathology* 50:269–276.

Brown, R. S. 1977. The Redevelopment of Quonset/Davisville: An Environmental Assessment. Technical Appendix No. 4. Histopathological Findings in *Mya arenaria* and *Mercenaria mercenaria* Samples from Quonset Point/Davisville, Rhode Island." Marine Technical Report No. 55, Coastal Resources Center, University of Rhode Island, Narragansett, RI.

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Brown, R. S., R. E. Wolke, C. W. Brown, and S. B. Saila. 1979. "Hydrocarbon Pollution and the Prevalence of Neoplasia in New England Soft-Shell Clams (*Mya arenaria*)." in *Animals as Monitors of Environmental Pollutants*, National Academy of Science, Washington, DC, pp 41–51.

Brown, R. S., R. E. Wolke, and S. B. Saila. 1976. "Preliminary Report on Neoplasia in Feral Populations of the Soft Shell Clam, *Mya arenaria*: Prevalence, Histopathology and Diagnosis," in *Proceedings of the First International Colloquium on Invertebrate Pathology*, Kingston, Ontario, Canada, pp. 151–158.

Brown, R. S., R. E. Wolke, S. B. Saila, and C. W. Brown. 1977. "Prevalence of Neoplasia in ten New England Populations of the Soft Shell Clam, *Mya arenaria*." *Annals of the New York Academy of Science* 298:522–534.

Carrano, A. V., L. H. Thompson, P. A. Lindl, and J. L. Minkler. 1978. "Sister Chromatid Exchange as an Indicator of Mutagenesis." *Nature* (London) 271:551–553.

Connolly, J. P. 1991. "Application of a Food Chain Model to Polychlorinated Biphenyl Contamination of the Lobster and Winter Flounder Food Chains in New Bedford Harbor." *Environmental Science and Technology* 25:760–770.

Conover, R. J. 1966. "Assimilation of Organic Matter by Zooplankton," *Limnology and Oceanography* 11:338–354.

Cooper, K. R., R. S. Brown, and P. W. Chang. 1982. "The Course and Mortality of a Hematopoietic Neoplasm in the Soft-Shell Clam, *Mya Arenaria*." *Journal Invertebrate Pathology* 39:149–157.

Dinnel, P., Q. Stober, M. Letourneau, W. Roberts, S. Felton, and R. Nakatani. 1983. "Methodology and Validation of a Sperm Cell Toxicity Test for Testing Toxic Substances in Marine Waters." Final Report. Grant R/TOX. FRI-UW-83. University of Washington Sea Grant Program in cooperation with U. S. Environmental Protection Agency, Seattle, WA.

Eichelberger, J. W., L. E. Harris, and W. L. Budde. 1975. "Chromatography-Mass Spectrometry Systems." *Analytical Chemistry* 7:995–1000.

Eisler, R., M. M. Barry, R. L. Lapan, Jr., G. Telek, E. W. Davey, and A. E. Soper. 1978. "Metal Survey of the Marine Clam *Pitar morrhuana* Collected Near a Rhode Island (USA) Electroplating Plant." *Marine Biology* 45:311–317.

Farley, C. A., S. V. Otto, and C. L. Reinisch. 1986. "New Occurrence of Epizootic Sarcoma in Chesapeake Bay Soft-Shell Clams, *Mya arenaria*." U. S. Fishery Bulletin 84:851–857.

Farley, C. A., D. L. Plutschak, and R. F. Scott. 1991. "Epizootiology and Distribution of Transmissible Sarcoma in Maryland Soft-Shell Clams, *Mya arenaria*," 1984–1988. *Environmental Health Perspectives* 90:35–41.

Farrington, J. W., R. W. Risebrough, P. L. Parker, A. C. Davis, B. de Lappe, K. Winters, D. Boatwright, and N. Frew. 1982. "Hydrocarbons, Polychlorinated Biphenyls, and DDE in Mussels and Oysters from the U.S. Coast, 1976–1978—The Mussel Watch." Woods Hole Oceanographic Institute Technical Report WHOI-82-42.

Fries, C., and M. R. Tripp. 1976. "Effects of Phenol on Clams." U.S. National Marine Fisheries Service. Marine Fisheries Review 38:10–11.

Gardner, G. R., and R. J. Pruell. 1987. "A Histopathological and Chemical Assessment of Winter Flounder, Lobster, and Soft-Shelled Clams Indigenous to Quincy Bay, Boston Harbor and an *In Situ* Evaluation of Oysters Including Sediment (Surface and Cores) Chemistry." Final Report Prepared for the U. S. Environmental Protection Agency, Region I. Environmental Research Laboratory, Narragansett, RI.

Gardner, G. R., P. P. Yevich, A. R. Malcolm, and R. J. Pruell. 1987. "Carcinogenic Effects of Black Rock Harbor Sediment on American Oysters and Winter Flounder." Project Report to the National Cancer Institute, Collaborative Program on Environmental Cancer. U. S. Environmental Protection Agency, Narragansett, RI.

Gentile, J. H., W. R. Munns, Jr., G. G. Pesch, and K. J. Scott. 1988a. "A Risk Characterization for the Unconfined Aquatic Disposal of Dredged Material." Report prepared for the U. S. Environmental Protection Agency, Office of Marine and Estuarine Protection. Environmental Research Laboratory, Narragansett, RI.

Gentile, J. H., G. G. Pesch, J. Lake, P. P. Yevich, G. Zaroogian, P. Rogerson, J. Paul, W. Galloway, K. Scott, W. Nelson, D. Johns, and W. Munns. 1988b. "Synthesis of Research Results: Applicability and Field Verification of Predictive Methodologies for Aquatic Dredged Material Disposal." Technical Report D-88-5, prepared for the U. S. Army Engineer Waterways Experiment Station, Vicksburg, MA, by the U. S. Environmental Protection Agency Environmental Research Laboratory, Narragansett, RI.

Germano, J. D. 1983. "High Resolution Sediment Profiling with REMOTS Camera System." *Sea Technology* 24:35–41.

Gleason, T. R., and C. Mueller. 1989. "Work/Quality Assurance Project Plan [for the] Risk Assessment Pilot Study, Naval Construction Battalion Center, Davisville, RI." Prepared for the U. S. Environmental Protection Agency Environmental Research Laboratory-Narragansett by Science Applications International Corporation, Narragansett, RI.

Goldberg, E. D., V. T. Bowen, J. W. Farrington, G. Harvey, J. H. Martin, P. L. Parker, R. W. Riseborough, W. Robertson, E. Schneider, and E. Gamble. 1978. "The Mussel Watch." *Environmental Conservation* 5:101–125.

Grovhoug, J. G., P. F. Seligman, G. Vafa, and R. L. Fransham. 1986. "Baseline Measurements of Butyltin in U. S. Harbors and Estuaries." in *Proceedings of Oceans 86*, Vol. 4, *Organotin Symposium*, pp. 1283–1289.

Hansen, D., K. J. Scott, M. Redmond, and W. Berry. 1986. "Preliminary Data Report—New Bedford Harbor Project." Prepared for USEPA Region I by the EPA Environmental Research Laboratory, Narragansett, RI.

Heddle, J. A., M. Hite, B. Kirkhart, K. Mavournin, J. T. MacGregor, G. W. Newell, and M. F. Salmone. 1983. The Induction of Micronuclei as a Measure of Genotoxicity, a Report of the U. S. Environmental Protection Agency Gene-Tox Program. Mutation Research 123:61–118.

Hillel, D. 1982. *Introduction to Soil Physics*. Academic Press, London.

Hoffman, E. J. 1988. "The First Year of the Narragansett Bay Project: Results and Recommendations." Report Prepared for the Narragansett Bay Project Management Committee by the University of Rhode Island, Narragansett, RI.

Humphrey, B., and D. Hope. 1987. "Analysis of Water, Sediments and Biota for Organotin Compounds." in *Proceedings of Oceans 87*, Vol. 4, *International Organotin Symposium*, pp. 1348–1351.

Karickhoff, S. W., D. S. Brown, and T. A. Scott. 1979. "Sorption of Hydrophobic Pollutants on Natural Sediments." *Water Research* 13:421–428.

Kingston, H. M., and L. B. Jassie. 1986. "Microwave Energy for Acid Decomposition at Elevated Temperatures and Pressures Using Biological and Botanical Samples." *Analytical Chemistry* 58:2534–2541.

Klaassen, C. D., M. O. Ambur, and J. Doull (eds.). 1986. *Toxicology*. Macmillan Publishing, New York.

Latt, S. A. 1974. "Sister Chromatid Exchanges, Indices of Human Chromosome Damage and Repair: Detection by Fluorescence and Induction by Mitomycin C." Proceedings of the National Academy of Science, Washington, DC, 71:3162–3166.

Latt, S. A., J. Allen, S. E. Bloom, A. Carrano, E. Falke, D. Kram, E. Schneider, R. Schreck, R. Tice, B. Whitfield, and S. Wolff. 1981. "Sister Chromatid Exchanges: A Report of the Gene-Tox Program." *Mutation Research* 87:17–62.

Long, E. R. and L. G. Morgan. 1990. "The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program." NOAA Technical Memorandum NOS OMA 52.

Lowry, O. H., N. J. Rosenberg, A. L. Farr, and R. J. Randall. 1951. "Protein Measurement with the Folin Phenol Reagent." *Journal Biological Chemistry* 193:265–271.

Malcolm, A. R., L. J. Mills, and E. J. McKenna. 1985. "Effects of Phorbol Myristate Acetate, Phorbol Dibutyrate, Ethanol, Dimethylsulfoxide, and Seven Metabolites of Phenol on Metabolic Cooperation Between Chinese Hamster V79 Lung Fibroblasts." *Cell Biology and Toxicology* 1:269–283.

Munns, W. R. Jr., J. F. Paul, V. J. Bierman, Jr., W. R. Davis, W. B. Galloway, G. L. Hoffman, P. F. Rogerson, and R. J. Pruell. 1988. "Exposure Assessment Component of the Field Verification Program: Overview and Data Presentation." U. S. Environmental Protection Agency Technical Report EPA-600/6-89/003, Narragansett, RI.

Munns, W. R., Jr., H. A. Walker, and J. F. Paul. 1989. "An Ecological Risk Assessment Framework for Examining the Impacts of Oceanic Disposal." in *Proceedings of Oceans 89*, Vol. 2, *Ocean Pollution*, pp. 664–669.

Nacci, D., E. Jackim, and R. Walsh. 1986. "Comparative Evaluation of Three Rapid Marine Toxicity Tests: Sea Urchin Early Embryo Growth Test, Sea Urchin Sperm Cell Toxicity Test and Microtox." *Environmental Toxicology and Chemistry* 5:521–525.

Nakashima, S., R. E. Sturgeon, S. N. Willie, and S. S. Berman. 1988. "Acid Digestion of Marine Samples for Trace Element Analysis Using Microwave Heating." *Analyst* 13:159–163.

Naval Energy and Environmental Support Activity (NEESA). 1984. "Initial Assessment Study of Naval Construction Battalion Center Davisville, Rhode Island." NEESA 13-070, Port Hueneme, CA.

Nelson, W. G. 1989. "A Framework for Real-Time Decision-Making—New Bedford Harbor Pilot Study." EPA-600/8-89/084. U. S. Environmental Protection Agency, Narragansett, RI.

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Nelson, W. G., D. K. Phelps, W. B. Galloway, P. F. Rogerson, and R. J. Pruell. 1987. "Effects of Black Rock Harbor Dredged Material on the Scope for Growth of the Blue Mussel, *Mytilus Edulis*, After Laboratory and Field Exposure." Technical Report D-87-7 prepared for the U. S. Army Engineer Waterways Experiment Station, Vicksburg, MA, by the U. S. Environmental Protection Agency Environmental Research Laboratory, Narragansett, RI.

Oprandy, J. J., P. W. Chang, A. D. Provost, K. R. Cooper, R. S. Brown, and V. J. Yates. 1981. "Isolation of a Viral Agent Causing Hematopoietic Neoplasia in the Soft-Shell Clam, *Mya arenaria*." *Journal Invertebrate Pathology* 38:45–51.

Oshida, P., T. Goochey, and A. Mearns. 1981. "Effects of Municipal Wastewater on Fertilization, Survival, and Development of the Sea Urchin, *Strongylocentrotus purpuratus*," in *Biological Monitoring of Marine Pollutants* (F. Vernberg, A. Calabrese, F. Thurberg and W. Vernberg, eds.), Academic Press, New York, pp. 389–402.

Patterson, K. Y., C. Veillon, and H. M. Kingston. 1988. In *Introduction to Microwave Sample Preparation: Theory and Practice* (H. M. Kingston and L. B. Jassie, eds.), American Chemical Society, Washington, DC.

Paul, J. F. 1987. "Risk Assessment Methods for 106-Mile Ocean Disposal Site." Report prepared for the U. S. Environmental Protection Agency, Office of Marine and Estuarine Protection. Environmental Research Laboratory, Narragansett, RI.

Perry, P. E., and S. Wolff. 1974. "New Giemsa Method for the Differential Staining of Sister Chromatids." *Nature* 251:156–158.

Phelps, D. K., and W. B. Galloway. 1980. "A Report on the Coastal Environmental Assessment Stations (CEAS) Program." Rapport et Process-Verbaux des Reunions, Counseil International pour l'Exploration de la Mer 179:76–81.

Pruell, R. J., W. Nelson, R. Palmquist, S. Fluck, and R. Bowen. 1988a. "New Bedford Harbor Pilot Study Preoperational Monitoring Progress Report: PCB Concentrations in *Mytilus edulis* from the First and Second Preoperational Mussel Deployments." Progress report prepared for the U. S. Environmental Protection Agency, Region I. Environmental Research Laboratory, Narragansett, RI.

Pruell, R. J., C. B. Norwood, R. D. Bowen, R. E. Palmquist, and S. J. Fluck. 1988b. "Organic Contaminants in Quahogs, *Mercenaria mercenaria*, Collected from Narragansett Bay." Final report prepared for the Narragansett Bay Project. Environmental Research Laboratory, Narragansett, RI.

PTI. 1987. "Guidance Manual for Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish: Executive Summary." Report prepared for the U. S. Environmental Protection Agency, Office of Marine and Estuarine Protection. PTI Environmental Services, Inc., Seattle, WA.

PTI. 1988. "Sediment Quality Values Refinement: Tasks 3 and 5—1988 Update and Evaluation of Puget Sound AET." Report prepared for the U. S. Environmental Protection Agency. PTI Environmental Services, Inc., Seattle, WA.

Reinisch, C. L., A. M. Charles, and A. M. Stone. 1984. "Epizootic Neoplasia in Soft-Shell Clams Collected from New Bedford Harbor." *Hazardous Waste* 1:73–81.

Rhoads, D. C., and J. D. Germano. 1982. "Characterization of Organism-Sediment Relations Using Sediment Profile Imaging: An Efficient Method of Remote Ecological Monitoring of the Seafloor (REMOTS (TM) System)." Marine Ecology Progress Series 8:115–128.

Robohm, R. A., and M. F. Nitkowski. 1974. "Physiological Response of the Cunner, *Tautogolabrus Adspersus*, to Cadmium. IV. Effects on the Immune Response." NOAA Technical Report NMFS SSRF-681 pp. 15–20.

Rosen, J. S., D. Sheehan, and R. Petrocelli. 1988. "Data Management Plan [for the] Risk Assessment Pilot Study, Naval Construction Battalion Center, Davisville, RI." Report prepared for the U. S. Environmental Protection Agency Environmental Research Laboratory, Narragansett, RI. Computer Sciences Corporation, Narragansett, RI.

Rugg, T., and P. Feldman. 1980. *Mathematics Programs in TRS-80 Programs*. Dilithium Press, Forest Grove, OR, pp. 185–194.

SAIC. 1989. "Narragansett Bay Sediment Quality Survey, August 1988." SAIC Report No. SAIC-89-7553&220, Science Applications International Corporation, Newport, RI.

Saila, S. B., E. Lorda, and H. A. Walker. 1979. "A Study of the Incidence of Soft Shell Clam Diseases in Relation to Pollution History of 24 Locations on the East Coast. Summary of Statistical Analyses, Vol. 1–3." Report to the American Petroleum Institute, prepared by the University of Rhode Island, Kingston, RI.

Seligman, P. F., J. G. Grovhoug, A. O. Valkirs, P. M. Stang, R. F. Fransham, M. O. Stallard, B. Davidson, and R. F. Lee. 1989. "Distribution and Fate of Tributyltin in the United States Marine Environments." *Appl. Organom. Chem.* 3:31–47.

Sinderman, C. J. 1984. "Fish and Environmental Impacts." *Arch. Fisch Wiss.* 35:125–160.

Stallard, M. O., S. Y. Cola, and C. A. Dooley. 1989. "Optimization of Butyltin Measurements for Seawater, Tissue, and Marine Sediment Samples." *Applied Organometallic Chemistry* 3:105–114.

Stang, P. M., and P. F. Seligman. 1987. "*In Situ* Adsorption and Desorption of Butyltin Compounds from Pearl Harbor, Hawaii Sediment." in *Proceedings of Oceans 87*, Vol. 4, *International Organotin Symposium*, pp. 1386–1391.

Taylor, J. H., P. S. Woods, and W. C. Hughes. 1957. The Organization and Duplication of Chromosomes as Revealed by Autoradiographic Studies Using Tritium-Labeled Thymidine." Proceedings of the National Academy of Science Washington, DC, 43:122–128.

TRC Environmental Consultants, Inc. 1986. "Verification Step of the Confirmation Study for Naval Construction Battalion Center, Davisville, Rhode Island." Report prepared for Northern Division, Naval Facilities Engineering Command. TRC Project Report No. 3006-N81-10, TRC Environmental Consultants, Inc., East Hartford, CT.

Uhler, A. D., T. H. Coogan, K. S. Davis, G. S. Durell, W. G. Steinhauer, S. Y. Freitas, and P. D. Boehm. 1989. Findings of Tributyltin, Dibutyltin, and Monobutyltin in Bivalves from Selected U. S. Coastal Waters." *Environmental Toxicology and Chemistry* 8:971–979.

U. S. EPA. 1980. "Ambient Water Quality Criteria for Polychlorinated Biphenyls." EPA 440/5-80-068.

U. S. EPA. 1985a. "Ambient Water Quality Criteria for Copper—1984." Office of Water Quality Criteria and Standards Division, Washington, DC. no. 440/5-84-031, 142 pages.

U. S. EPA. 1985b. "Ambient Water Quality Criteria for Lead—1984." EPA 440/5-84-027.

U. S. EPA. 1985c. "Ambient Water Quality Criteria for Cadmium—1984." EPA 440/5-84-032.

U. S. EPA. 1986. "Ecological Risk Assessment." Hazard Evaluation Division Standard Evaluation Procedure, Office of Pesticide Programs, EPA-540/9-85-001, Washington, DC.

U. S. EPA. 1988. "Review of Ecological Risk Assessment Methods." Office of Policy, Planning and Evaluation, EPA/230-10-88-041, Washington, DC.

Wade, T. L., B. Garcia-Romero, and J. M. Brooks. 1988. "Tributyltin Contamination in Bivalves from United States Coastal Estuaries." *Environmental Science and Technology* 22:1488–1493.

Walker, H. A., E. Lorda, and S. B. Saila. 1981. "A Comparison of the Incidence of Five Pathological Conditions in Soft-Shell Clams, *Mya arenaria*, from Environments with Various Pollution Histories." *Marine Environmental Research* 5:109–123.

Warren, C. E., and G. E. Davis. 1967. "Laboratory Studies on the Feeding, Bioenergetics and Growth of Fish." in *The Biological Basis of Freshwater Fish Production* (S. D. Gerking, ed.), Blackwell Scientific Publications, Oxford, pp. 174–219.

Weber, J. H., O. F. X. Donard, L. Randall, and J. S. Han. 1986. "Speciation of Methyl- and Butyltin Compounds in the Great Bay Estuary (N. H.)." in *Proceedings of Oceans 86*, Vol. 4, *Organotin Symposium*, pp. 1280–1282.

Widdows, J., D. K. Phelps, and W. B. Galloway. 1981. "Measurement of Physiological Condition of Mussels Transplanted Along a Pollution Gradient in Narragansett Bay." *Marine Environmental Research* 4:181–194.

Yevich, P. P., C. A. Yevich, K. J. Scott, M. Redmond, D. Black, P. S. Schauer, and C. E. Pesch. 1986. "Histopathological Effects of Black Rock Harbor Dredged Material on Marine Organisms." Technical Report D-86-1 prepared for the U. S. Army Engineer Waterways Experiment Station, Vicksburg, MA, by the U. S. Environmental Protection Agency Environmental Research Laboratory, Narragansett, RI.

Yotti, L. P., C. C. Chang, and J. E. Trosko. 1979. "Elimination of Metabolic Cooperation in Chinese Hamster Cells by a Tumor Promoter." *Science* 206:1089–1091.

APPENDIX A

MEMORANDUM OF AGREEMENT

BETWEEN NOSC AND ERLN

IN REPLY REFER TO:
5090
Ser 522/38
7 OCT 1988

From: Commander, Naval Ocean Systems Center
To: Director, Environmental Protection Agency-Environmental
Research Laboratory

Subj: MEMORANDUM OF AGREEMENT FOR COOPERATIVE RESEARCH AND
DEVELOPMENT FOR ECOLOGICAL RISK ASSESSMENTS

Encl: (1) Memorandum of Agreement Between the Environmental Protection
Agency-Environmental Research Laboratory and the Naval Ocean
Systems Center dtd 19 Sep 88

1. Enclosure (1) is the Memorandum of Agreement (MOA) between the Naval
Ocean Systems Center (NAVOCEANSYSCEN) and the Environmental Protection
Agency-Environmental Research Laboratory (EPA-ERL) regarding cooperative
research and development for ecological risk assessments. The agreement
was prepared in consultation with Mr. Allan D. Beck, Senior Science
Advisor, EPA-ERL.

2. Upon concurrence, please sign and return the original to Dr. S.
Yamamoto, Head, Environmental Sciences Division, Code 52, Naval Ocean
Systems Center, San Diego, CA 92152-5000.

3. For further information regarding this MOA, please contact Mr. Robert K.
Johnston, Code 522, (619) 553-5330, who will coordinate this understanding.

E. G. SCHWEIZER

Copy to:
OASN (S&L) (N. Stehle)
OPNAV 045 (D. Olson)
OGC (M. Robertson)
NAVFAC 183 (P. Yaroschak)
NORTHDIV 1421 (T. Schekels)

RECEIVED

_10/17/88_

**OFFICE OF THE DIRECTOR
EPA ENVIRONMENTAL RESEARCH LABORATORY
NARRAGANSETT, RI**

A-3

MEMORANDUM OF AGREEMENT BETWEEN

U. S. NAVY

Naval Ocean Systems Center

Environmental Sciences Division, Code 52

San Diego, CA 92152-5000

AND

U. S. Environmental Protection Agency

Environmental Research Laboratory

South Ferry Road

Narragansett, RI 02882

COOPERATIVE RESEARCH AND DEVELOPMENT FOR

ECOLOGICAL RISK ASESSMENTS

I. Authority

Pursuant to the authority contained in Section 7 of the Economy Act of 1932, 31 U.S.C. 1535, the U. S. Navy Naval Ocean Systems Center (NAVOCEANSYSCEN) and the U. S. Environmental Protection Agency Environmental Research Laboratory (EPA-ERL) enter into this technical agreement. By execution of this agreement, NAVOCEANSYSCEN certifies that the agreement is in the best interest of the Government and the services ordered hereunder cannot be provided as conveniently or as cheaply by a commercial enterprise.

II. Background

The Navy is required by the Comprehensive Environmental Resource Conservation and Liability Act, as amended by the Superfund Amendment and Reauthorization Act of 1986 (CERCLA), to remove or arrange for the removal of, and provide for remedial action relating to hazardous substances released or threatened to be released on Navy facilities or take other response measures necessary to protect the public health or welfare of the environment. 42 U.S.C. 9604(a). CERCLA further provides for research, development, and demonstration of "methods and technologies to detect hazardous substances in the environment and basic biological chemical and physical methods to reduce the amount and toxicity of hazardous substances". 42 U.S.C. 9660 (a)(1)(A)(iii).

To support the Navy's efforts to meet the requirements of CERCLA, a number of research and development projects were initiated by NAVOCEANSYSCEN. The objectives of this research initiative have been to provide technologies to measure and define the extent of hazardous waste impact, assess the toxicological and biological effects of hazardous wastes and to develop tools to detoxify and bioremediate these wastes.

The major emphasis of the R&D initiative is to provide

better tools for monitoring and assessing hazardous waste impact
at past disposal sites on Navy facilities, including sites in
coastal and estuarine areas. The acquisition of monitoring and
assessment information is critical to the Navy's program because
such information is required to determine (1) whether or not an
environmental problem exists, (2) what the extent of the problem
might be, (3) what must be done about the problem, and (4) how
successful corrective action will solve the problem.

The Environmental Research Laboratory (EPA-ERL) is the
Environmental Protection Agency's center for marine, coastal, and
estuarine water quality research. The primary research emphasis
at EPA-ERL is on providing the scientific base for marine risk
assessment. EPA-ERL is responsible for studying the ecological
effects of estuarine and marine hazardous waste disposal and the
effects from discharge of complex wastes, dredged materials, and
other wastes. The EPA-ERL also supports development of water use
designation and water quality criteria for estuarine and marin
water and sediments and environmental assessments of ocean
discharges. A major portion of the research involves the
d velopment, evaluation, and application of techniques and test
systems for measuring and predicting the transport, fate, and the
biological and ecosystem effects of complex waste in estuarine
and marine systems.

It is the intent of NAVOCEANSYSCEN and EPA-ERL to conduct a
cooperative effort in selected research and monitoring activities

related to conducting ecological risk assessments at potentially impacted aquatic sites on or adjacent to Navy facilities over a five year period, from Fiscal Year 1989 through Fiscal Year 1993. It is also the intent of NAVOCEANSYSCEN and EPA-ERL to jointly develop a scope of work and to budget for the research and monitoring activities related to these ecological risk assessments for each separate project.

III. Objective

The objective of this agreement will be to develop cooperative research and monitoring activities related to conducting ecological risk assessment at potentially impacted aquatic sites on or adjacent to Navy facilities. Information developed in the course of conducting ecological risk assessments at impacted sites will be used to develop guidance and case studies for ecological risk assessments at other Navy and non-Navy aquatic sites.

IV. Duration of the Agreement

This agreement, when accepted by NAVOCEANSYSCEN and EPA-ERL, will have an effective date from Fiscal Year 1989 through Fiscal Year 1993. With regard to work that NAVOCEANSYSCEN is responsible for funding under this agreement, in the event of

termination by NAVOCEANSYSCEN, NAVOCEANSYSCEN shall reimburse
EPA-ERL for all costs incurred (including costs related to
terminating outstanding obligations) by EPA-ERL to the extent
such costs have not been previously reimbursed and to the extent
such costs do not exceed the amounts NAVOCEANSYSCEN has agreed to
provide EPA-ERL.

V. Scopes of Work

Cooperative research and monitoring activities related to
conducting ecological risk assessments at potentially impacted
aquatic sites on or adjacent to Navy facilities will be conducted
as described in separate scopes of work which will be developed
by NAVOCEANSYSCEN and EPA-ERL for each project. Delivery
schedules which specify the level and type of assistance and
support will be detailed in such scopes of work.

VI Management

This agreement is to be implemented under the authority of
the Commander, NAVOCEANSYSCEN, as delegated to the Environmental
Sciences Division Head, and the Director of EPA-ERL, and with the
coordination and approval of the Commanding Officer of the host
activity. No significant changes or modifications in concept,
approach, direction, or scope of the agreement will be made

without prior written concurrence of the Commander, NAVOCEANSYSCEN, the Director of EPA-ERL, and the Commanding Officer of the host activity. With such concurrence, the agreement may be modified as appropriate at any time. Amendments will be made via a clear and complete description of the modification, identifying it as an amendment to this agreement and jointly signed by all responsible parties. Technical details for implementation of the agreement will be developed cooperatively by NAVOCEANSYSCEN and EPA-ERL and set forth in a detailed scope of work. Ultimate responsibility and authority for work completed under this technical agreement with DOD/NAVY funds rests with NAVOCEANSYSCEN, with the coordination and approval of the Activity Commanding Officer.

The Head, Environmental Sciences Division, by direction of the Commander, NAVOCEANSYSCEN is responsible for: (1) coordinating with and obtaining approval from the Activity Commander for all work to be conducted onboard the activity; (2) monitoring the technical progress of the studies, including the surveillance and assessment of performance and recommending changes; (3) interpreting the Memorandum of Agreement and Scope of Work; (4) performing technical evaluations and inspections as appropriate; (5) conducting on-site evaluations of risk assessment protocols, analytical methodologies, and monitoring procedures and conducting inter-laboratory comparisons with EPA-ERL; (6) assisting both agencies in the resolution of problems encountered during the agreement period.

The director, EPA-ERL is responsible for: (1) implementing the research within the established time and funding constraints; (2) producing reports according to schedule; (3) ensuring all research conducted by EPA-ERL is of high technical quality and appropriate to meet the objectives of the studies, including recommendations for modifications in approach as appropriate; (4) coordinating and communicating research results to the Activity Commander and Technical Review Committee as appropriate.

The Commanding Officer of the activity where the study is to be conducted is responsible for: (1) granting final approval for that portion of the Scope of Work to be conducted at his activity; (2) providing support and assistance in meeting the study objectives as required; (3) disseminating all data and information developed from the studies to the requisite regulatory agencies, citizen groups, and general public, as appropriate.

VII. Progress Review

Progress reports and other deliverables will be produced in accordance with the Scope of Work. Progress reports will describe the progress and status of each study plan, including such items as activities in progress or completed, key milestones achieved, anticipated problem areas and their effects on the

project schedule, fiscal status, meetings held or attended, and review recommendations.

The Director, EPA-ERL and Commander, NAVOCEANSYSCEN and their staffs will keep the Activity Commanding Officer fully informed and up to date on all aspects of all activities under this agreement. The Activity Commanding Officer shall review progress to assure the study meets with the needs of the activity. On the basis of this information, any aspect of the work may be reviewed and revised as deemed appropriate. Such revisions will be made in accordance with Section VI of this agreement.

An annual review meeting on work under this agreement will involve technical presentations on work accomplished on each Scope of Work, current status, and future plans, and will also consider managerial and other aspects of the agreement.

VIII. Funding

Interagency funding will be provided in accordance with the Scope of Work developed for each proposed study. Funding by NAVOCEANSYSCEN and EPA-ERL is subject to the U. S. Government appropriation process. No responsibility is assumed by NAVOCEANSYSCEN for costs expended by EPA-ERL beyond the funding made available by NAVOCEANSYSCEN. Should funding changes s

require, this agreement will be modified to appropriately adjust the work to be conducted. NAVOCEANSYSCEN operates under a goal established by the Chief of Naval Operations that funds made available for this study will be effectively obligated and expended in the fiscal year for which they were appropriated by Congress. Progress in meeting this goal will be monitored by NAVOCEANSYSCEN through funding data provided in the Progress Reports. Funding transfers are to be by appropriate acceptable documents.

IX. Materials

Materials will be furnished by NAVOCEANSYSCEN and EPA-ERL in accordance with the Scope of Work.

X. Products

Products and deliverables will be produced in accordance with the Scope of Work. Copies of the final draft reports will be submitted for technical and editorial review by the Commanding Officer of the studied activity and NAVOCEANSYSCEN. Comments will be furnished within eight weeks and the technical reports will be finalized by the authors after consideration of comments. Technical findings will not be subject to revision, but recommendations for changes in all areas other than technical findings, will be incorporated into the final reproduction copy.

ALL FINAL TECHNICAL REPORTS MUST BE APPROVED FOR PUBLIC RELEASE
BY THE HOST ACTIVITY COMMANDING OFFICER BEFORE PUBLICATION BY
NAVOCEANSYSCEN OR EPA-ERL. All necessary EPA and Navy
headquarters approvals for publication will be obtained in such a
manner as to not affect publication schedules. All technical
reports will be thorough, comprehensive descriptions and
discussions of the research on the respective topics, including
the relationship of the finding to the open literature and
appropriate NAVOCEANSYSCEN and EPA reports.

Publication of findings in the refereed literature, after
publication by NAVOCEANSYSCEN or EPA-ERL and approval by the host
Activity Commanding Officer, is strongly encouraged and is
considered essential to realizing full benefits from the
research. Copies of all reports, papers, journal articles, and
presentations of data describing work conducted during the
studies should be provided to the Commander, NAVOCEANSYSCEN, via
the Activity Commanding Officer, after approval by the Director
of EPA-ERL, at the time the item is first submitted to the
publishing or presenting body for review. This is essential so
that all concerned individuals are fully aware of all
publications emanating from the studies. This act of
notification does not imply any control by the Navy over non-
g vernmental publications or presentations. Additionally, in
order to prevent potential copyright questions concerning
subsequent incorporation of material from the above publication
in Technical Reports, all such publications will contain a

reference to the appropriate T chnical Report as "in press".
There will also be an acknowledgement that some parts of the
publication have been taken from the Technical Report.

XI. Approval

The undersigned concur with the intent and provisions of
this agreement.

_____   _____
E. G. SCHWEIZER, CAPT USN   7 OCT 88
Commander   Date
Naval Oceans Systems Center
San Diego, CA

_____   _____
Norbert A. Jaworski, Director   10/18/88
Environmental Research Laboratory   Date
Environmental Protection Agency
Narragansett, RI

APPENDIX B

ANNOTATED BIBLIOGRAPHY FOR ALLEN HARBOR

American Petroleum Institute. 1984. Field and laboratory studies to define the occurrence of neoplasia in the soft-shell clam, *Mya arenaria*. API Publication No. 4345. American Petroleum Institute, Washington, D.C. (Borrowed from Dr. Chang, URI 9/21/89)

A synthesis of many of the soft-shell clam neoplasia papers cited previously. The major findings include: the neoplasia has been found over a wide geographic area; Allen Harbor has a much greater percentage of clams exhibiting the neoplasia than other sites in Rhode Island; and a virus believed to cause the neoplasia has been isolated from neoplastic clams collected in Allen Harbor.

Brown, R.S. 1977. The redevelopment of Quonset/Davisville: An environmental assessment. Technical Appendix No. 4. Histopathological findings in *Mya arenaria* and *Mercenaria mercenaria* samples from Quonset Point/Davisville, Rhode Island. Marine Tech. Rept. No. 55, Univ. of Rhode Island, Narragansett, RI, Coastal Resources Center, 4pp. (C)

Histological analysis of soft-shell clams and quahogs from Quonset/Davisville. The soft-shells were collected in Allen Harbor (AH), the Quahogs outside of AH. Thirty-seven percent (37%) of the soft-shell clams were reported to have hematopoietic neoplasia.

Brown, R.S., R.E. Wolke and S.B. Saila. 1976. Preliminary report on neoplasia in feral populations of the soft shell clam, *Mya arenaria*: Prevalence, histopathology and diagnosis. In: Proc. of the First International Colloquium on Invertebrate Pathology, Queen's University, Kingston, Canada, pp. 151-158. (C)

A report of the prevalence of neoplasia from four sites in Narragansett Bay (including Wickford and East Greenwich, but not Allen Harbor). Microscopic examination of circulating blood cells was reported to be a simple, rapid, and reliable technique for diagnosis of the neoplasia.

Brown, R.S., R.E. Wolke, C.W. Brown, and S.B. Saila. 1979. Hydrocarbon pollution and the prevalence of neoplasia in New England soft-shell clams (*Mya arenaria*). In "Animals as Monitors of Environmental Pollutants,". Nat. Acad. Sci., Washington, D.C., pp 41-51. (ERLN Library)

This report contains essentially the same data set as the API report. The neoplasia is cited as being both chronic and malignant. The authors could not find conclusive evidence of a link between hydrocarbon pollution and the neoplasia, and instead suggest that an infectious agent may be involved. The percent of neoplastic clams found at six sites in Rhode Island, including Allen Harbor, are reported.

Brown, R.S., R.E. Wolke, S.B. Saila and C.W. Brown. 1977. Prevalence of neoplasia in ten New England populations of the soft shell clam, *Mya arenaria*. Ann. N.Y. Acad. Sci. 298: 522-534. (C)

Hematopoietic neoplasia was reported to be prevalent over a wide geographic area. Eighteen of 45 (40%) soft shell clams collected in Allen Harbor were found to have neoplasms. The authors suggest that the prevalence of neoplasms found in soft shell

clams may be related to the degree of hydrocarbon pollution. (C)

Cabelli, V.J. 1988. Microbial indicator levels in shellfish, water and sediments from the upper Narragansett Bay conditional shellfish-growing area. Final report prepared for the Narragansett Bay Project by the University of Rhode Island, Kingston, RI, 62pp.

Bacteriology for several stations in NB, including MV but excluding Allen Harbor. "Shellfish" are quahogs. (C)

Cooper, K.R. 1979. The hematopoietic neoplasm in the commercially important bivalve mollusk *Mya arenaria* (Linne). Ph.D dissertation, University of Rhode Island, Kingston, RI. 116pp.

The author reports a biphasic seasonal variation in the prevalence of hematopoietic neoplasia in soft shell clams collected in Allen Harbor. Peak prevalence occurred in October/November and April/May when greater than 40% of the clams were neoplastic. (URI LIBRARY)

Cooper, K.R., R.S. Brown, and P.W. Chang. 1982a. The course and mortality of a hematopoietic neoplasm in the soft-shell clam, *Mya arenaria*. J. Invert. Pathol. 39: 149-157. (C)

Results of a 20 month study of feral soft-shell clams from Allen Harbor demonstrated a biphasic seasonal pattern in prevalence and severity of neoplasia. Peak prevalence of neoplasia ranged from 39-43% and occurred during October/November and April. Two laboratory studies yielded equivocal results regarding the progression of the disease. At high levels of severity the disease was progressive and resulted in death, at intermediate levels the disease could be chronic or progressive, and at low levels of severity remission sometimes occurred.

Cullen, J.D. Jr. 1984. A biogeochemical survey: copper and nickel in *Mercenaria mercenaria*, relative to concentrations in the water column in a New England estuary. M.S. thesis University of Rhode Island, Kingston, RI, 141 pp. (C)

Study of the relationship between water column concentrations of nickel and copper and corresponding tissue levels in Quahogs. The author suggests that water column concentrations of the two metals can be estimated from their tissue concentrations in Quahogs. One sample site was located near Marsh Point, but no stations were near Allen Harbor.

Eisler, R., M.M. Barry, R.L. Lapan, Jr., G. Telek, E.W. Davey and A.E. Soper. Metal survey of the marine clam *Pitar morrhuana* collected near a Rhode Island (USA) electroplating plant. Mar. Biol. 45: 311-317. (C)

Farrington, J.W., and J.G. Quinn. 1973. Petroleum hydrocarbons in Narragansett Bay, I. Survey of hydrocarbons in sediments and clams (*Mercenaria mercenaria*). Estuar. Coast. Mar. Sci. 1: 71-79.

Hydrocarbon concentrations in clams and sediments from Narragansett Bay, including Mount View but not Allen Harbor. In general, concentrations decreased with increasing distance from the Providence River.

Ganz, A., and R. Sisson. 1977. The redevelopment of Quonset/Davisville: an environmental assessment. Technical Appendix No. 3. Inventory of the fisheries resources of the Quonset/Davisville area North Kingstown, Rhode Island. Mar. Tech. Rep. No. 55, Univ. of Rhode Island, Narragansett, RI, Coastal Resource Center, 20pp. (C)

> Soft-shell clams are reported to be moderately abundant ~20/m^2 in Allen Harbor (AH). The average density of quahogs in AH was reported to be 2.6/m^2.

Kern, F.G. 1986. Narragansett Bay Project: Quahog histopathology studies. Final report prepared for the U.S. Environmental Protection Agency by NOAA-NMFS, 25pp.

> Quahog pathology at several stations in Narragansett Bay, including Mount View and Greenwich Bay, but excluding Allen Harbor. (C)

Lorda, E., H.A. Walker and S.B. Saila. 1981. A severity index to assess and monitor the incidence of pollution related pathological conditions in marine organisms. Marine Environ. Res. 5: 93-108.

> A mathematically derived severity index analyzing the occurrence of 5 pathological conditions using 379 soft-shell clams collected in Allen Harbor. This severity index is used to rank sites in Walker et al. 1981. (C)

Pratt, S.D. Status of the hard clam fishery in Narragansett Bay. Report prepared for the Narragansett Bay Project by the University of Rhode Island, Narragansett, RI, 69pp. (C)

> Summarizes quahog information for Narragansett Bay, including catch, management, and biology.

Oprandy, J.J. 1982. Isolation and characterization of a virus causing hematopoietic neoplasia in the soft-shell clam, *Mya arenaria* (Linne). Ph.D dissertation, University of Rhode Island, Kingston, RI, 145pp.

> Isolation of a viral agent believed to be responsible for the neoplasia observed in soft shell-clams from Allen Harbor. (URI LIBRARY)

Oprandy, J.J., P.W. Chang, A.D. Provost, K.R. Cooper, R.S. Brown, and V.J. Yates. 1981. Isolation of a viral agent causing hematopoietic neoplasia in the soft-shell clam, *Mya arenaria*. J. Invert. Pathol. 38:45-51.

> Same description as Oprandy (1982).

Pratt, S.D. 1977. The redevelopment of Quonset/Davisville: An environmental assessment. Technical Appendix No. 2. Benthic biology of areas adjacent to the Quonset/Davisville base. Marine Tech. Rep. No. 55, Univ. of Rhode Island, Narragansett, RI, Coastal Resources Center, 32pp. (C)

> This paper contains a discussion of the intertidal and subtidal sediment composition and species diversity in Allen Harbor. The author notes that invertebrate competitors and predators of the soft-shell clam occur in low numbers in Allen Harbor. A summary table of organisms found in the tidal/mud flat adjacent to the landfill is included.

Pratt, S.D. 1980. Environmental assessment Davisville port expansion. Part C. Effects of development at Davisville, Rhode Island on the marine environment. Univ. of Rhode Island, Graduate School of Oceanography, Narragansett, RI, Coastal Resource Center, 55pp. (C)

This study was focused primarily on the Quonset/Davisville, but it does contain information on coliform levels in Allen Harbor as well as metals levels in feral soft-shell clams and quahogs.

Pruell, R.J., C.B. Norwood, R.D. Bowen, R.E. Palmquist and S.J. Fluck. 1988. Organic contaminants in quahogs, *Mercenaria mercenaria*, collected from Narragansett Bay. Final report prepared for the Narragansett Bay Project by the U.S. EPA Environmental Research Laboratory, Narragansett, RI, 29+pp. (C)

Organic levels in quahogs from several stations in NB, including MV but excluding Allen Harbor.

Saila, S.B., E. Lorda and H.A. Walker. 1979. A study of the incidence of soft shell clam diseases in relation to pollution history of 24 locations on the East Coast. Summary of statistical analyses, vol. 1-3. Report to the American Petroleum Institute, prepared by the University of Rhode Island, Kingston, RI. (COPY BORROWED FROM DR. CHANG, URI 9/21/89)

Thibault/Bubly Associates. 1987. Trace metals in quahog clams from Narragansett Bay. Final report prepared for the Narragansett Bay Project, 20pp.

Trace metal levels in quahogs from several stations in NB, including MV but excluding Allen Harbor. (C)

Walker, H.A., E. Lorda and S.B. Saila. 1981. A comparison of the incidence of five pathological conditions in soft-shell clams, *Mya arenaria*, from environments with various pollution histories. Marine Environmental Research 5: 109-123. (C)

A statistical treatment of data found in Saila et al. (1979) examining linkages between environmental contamination and pathology. Using the severity index of Lorda et al. (1981) Allen Harbor ranks third highest of the 17 sites studied.

Related Papers on Neoplasia in Soft-shell Clams

Brousseau, D.J. 1987. Seasonal aspects of sarcomatous neoplasia in *Mya arenaria* (soft-shell clam) from Long Island Sound. J. Invert. Pathol. 50: 269-276. (C)

The author reported epizootic levels of neoplasia (same disease as Allen Harbor) occurring in soft-shell clams from three sites in Connecticut. Over the course of the 2.5 year study, a "pronounced seasonal pattern" with peak prevalence of 45 to 60% occurring during the late fall and winter was noted.

Cooper, K.R., R.S. Brown, and P.W. Chang. 1982b. Accuracy of blood cytological

screening techniques for the diagnosis of a possible hematopoietic neoplasm in the bivalve mollusc, *Mya arenaria*. J. Invert. Pathol. 39: 281-289. (C)

Farley, C.A. 1976. Proliferative disorders in bivalve mollusks. Mar. Fish. Rev. 38(10): 30-33.

Twelve percent (12%) of the soft-shell clams sampled in Jones Creek, Annisquam River, Massachusetts were neoplastic.

Farley, C.A., S.V. Otto, and C.L. Reinisch. 1986. New occurrence of epizootic sarcoma in Chesapeake Bay soft-shell clams, *Mya arenaria*. U.S. Fish. Bull. 84(4): 851-857. (C)

This study describes the sudden widespread occurrence of neoplasia (same disease as Allen Harbor) in Chesapeake Bay soft-shell clams which had previously been documented as sarcoma-free. Peak prevalence of 42 to 65% were noted. The authors suggest that the infectious agent may have been introduced by transplantation of New England clams in Chesapeake Bay.

Farley, C.A., D.L. Plutschak, and R.F. Scott. In press. Epizootiology and range of transmissible sarcoma in Maryland soft-shell clams, *Mya arenaria*, 1984-1988. Journal of Environmental Health Perspectives.

Miosky, D.L., R.M. Smolowitz, and C.L. Reinisch. 1989. Leukemia cell specific protein of the bivalve mollusc *Mya arenaria*. J. Invert. Pathol. 48: 139-145.

Oprandy, J.J. and P.W. Chang. 1983. 5-Bromodeoxyuridine induction of hematopoietic neoplasia and retrovirus activation in the soft-shell clam, *Mya arenaria*. J. Invert. Pathol. 42:196-206. (C)

Otto, S.V. and C.A. Farley. 1976. Neoplasms in bivalve mollusks from the Upper Chesapeake Bay and adjoining tributaries. In: Proc. of the First International Colloquium on Invertebrate Pathology, Queen's University, Kingston, Canada, pp. 158. (C)

One neoplasm was reported for 1400 Chesapeake Bay soft-shell clams collected from 1969 to 1973.

Peters, E.C. 1988. Recent investigations on the disseminated sarcomas of marine bivalve molluscs. Amer. Fish. Soc. Spec. Pub. 18: 74-92. (C)

The term disseminated sarcoma refers to disease which had previously been termed hematopoietic neoplasia. The ontogeny of the neoplasia has not been elucidated. A table lists the geographic range over which the neoplasia has been observed in soft-shell clams (Chesapeake Bay to Nova Scotia). The author calls for more research to address the basic cellular biology of bivalves, the cellular identity of the neoplasia, mechanisms controlling blood cell formation, and the relationship of environmental stress to metabolic changes and to depression of defense mechanisms.

Reinisch, C.L., A.M. Charles, and A.M. Stone. 1984. Epizootic neoplasia in soft shell clams collected from New Bedford Harbor. Hazardous Waste 1(1): 73-81. (C)

The prevalence of neoplasia in soft-shell clams for two sites in Southern New

England ranged from 10 to 29%, while the prevalence for New Bedford Harbor soft-shells ranged from 18 to 90%. Detectable amounts of PCB were found to accumulate in the neoplastic cells from New Bedford Harbor clams.

Smolowitz, R.M. and C.L. Reinisch. 1986. Indirect peroxidase staining using monoclonal antibodies specific for Mya arenaria neoplastic cells. J. Invert. Pathol. 48: 139-145. (C)

Yevich, P.P. and C.A. Barszcz. 1976. Gonadal and hematopoietic neoplasms in *Mya arenaria*. Mar. Fish. Rev. 38(10): 42-43.

A description of hematopoietic neoplasia in soft-shell clams from Freeport, Maine, in an area contaminated with jet fuel.

Environmental Quality

Gardiner, W.E. 1977. The redevelopment of Quonset/Davisville: An environmental assessment. Technical Appendix No. 1. Marshes on the Quonset/Davisville Site. Mar. Tech. Rep. No. 55, Univ. Rhode Island, Narragansett, RI, Coastal Resource Center, 19pp. (C)

The marshland in and around Allen Harbor and Quonset/Davisville is mapped.

Hoffman, E.J. 1988. The first year of the Narragansett Bay Project: Results and recommendations. Report submitted to the Narragansett Bay Project Management Committee, University of Rhode Island, Narragansett, RI.

Hunt, C.D. et al. 1987. Narragansett Bay water quality monitoring and source strength measurements. Marine Ecosystems Research Laboratory, University of Rhode Island, Narragansett, RI.

Isaji, T. 1977. Influence of dredging on water circulation in the vicinity of Quonset/Davisville complex Narragansett Bay, Rhode Island. Report prepared for the Coastal Resources Center, University of Rhode Island, 10pp. (C)

SAIC. 1989. Narragansett Bay sediment quality survey, August 1988, Final Report. Prepared for The Narragansett Bay Project. SAIC Report No. SAIC-89/7553&220. Science Applications International Corporation, Newport, Rhode Island.

The three sites in Allen Harbor included in a Narragansett Bay sediment quality survey were reported to have excessive organic enrichment. Low *Clostridium perfringens* spore counts corresponding to these sites suggests that the organic loading is due to sources other than sewage input. Allen Harbor was not considered to be substantially impacted.

Management of Davisville and Narragansett Bay

Coastal Resource Center. 1977. The redevelopment of Quonset/Davisville an environmental

assessment. Marine Technical Report No. 55. Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI, 200pp. (C)

Coastal Resource Center. 1981. Environmental assessment Davisville port expansion. Prepared for The Rhode Island Department of Economic Development. Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI. (C)

Naval Energy and Environmental Support Activity (NEESA). 1984. Initial Assessment Study of Naval Construction Battalion Center Davisville, Rhode Island. NEESA 13-070, Port Hueneme, CA.

NOAA. 1987. Narragansett Bay: Issues, resources, status, and management. Proceedings of the NOAA Estuary-of-the-Month Seminar Series, No. 1, Washington, DC, 171 pp. (C)

This symposium covered aspects of Narragansett Bay management issues, circulation dynamics, pollution inputs, and economy.

TRC Environmental Consultants, Inc. 1986. Draft report, verification step, confirmation study, Naval Construction Battalion Center, Davisville, Rhode Island. Prepared for Northern Division, Naval Facilities Engineering Command, Philadelphia, PA. TRC Project No. 3006-N81-10. TRC Environmental Consultants, Inc., East Hartford, Connecticut. (C)

Includes background information which has been omitted in the final report.

TRC Environmental Consultants, Inc. 1986. Verification step of the Confirmation Study for Naval Construction Battalion Center, Davisville, Rhode Island. Report prepared for Northern Division, Naval Facilities Engineering Command. TRC Project Report No. 3006-N81-10, TRC Environmental Consultants, Inc., East Hartford, CT. (C)

U.S.G.S.A. 1978. Final environmental impact statement: administrative action, disposal of surplus federal military properties in Rhode Island; Quonset Point Naval Air Station, Construction Battalion Center (Davisville), Newport Naval Base.

This report contains a summary of site contamination data for the landfill at Allen Harbor and Calf Pasture Point. In addition, the results of the environmental assessment of the area are summarized.

APPENDIX C

SANITARY SURVEYS OF ALLEN HARBOR

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INTRODUCTION

Sewage sludges harbor concentrated numbers of microbiological indicators of fecal contamination which can survive for extensive periods of time in the environment. From 1946 to 1972, Quonset sewage treatment facility dumped between 11,000 and 13,800 cubic yards of sludge into the landfill. The potential for leachate migration of these microbiological indicators from the landfill area into the harbor is high. In addition to the landfill, several other known and suspected sources of fecal contamination may also impact the harbor.

The National Shellfish Sanitation Program (NSSP) requires that a sanitary survey be performed of every potential shellfish growing area. The sanitary survey is a microbiological evaluation of all actual and potential pollution sources and environmental factors which may impact water quality in shellfish growing areas. The five tube most probable number (MPN) and membrane filtration (mF) methods were employed to detect the presence of three microbiological indicators of sanitary quality: fecal coliforms, enterococci and *Clostridium perfringens* spores. Fecal coliform density, as determined by the MPN method, is the accepted standard for classification of shellfish growing waters. The NSSP requires that the geometric mean fecal coliform density, as determined by the MPN method, not exceed 14 colony forming units (CFU)/100 ml and that no more than 10 percent of the samples exceed a density of 43 CFU/100 ml. Although the mF method is not approved for shellfish water classification, it was used in this study to assess pollution loading from land stations. Enterococci density was employed as an alternative indicator of fecal pollution. This indicator is currently under consideration for use as a health affects standard for swimming waters. Finally, *Clostridium perfringens* spores, which are capable of surviving for long periods of time in the environment, were measured as an additional indicator of fecal pollution.

METHODS

Sample Stations

Locations of the sample stations chosen for this sanitary survey are shown in Figure C-1. Eleven land stations were examined as potential pollution sources to the harbor.
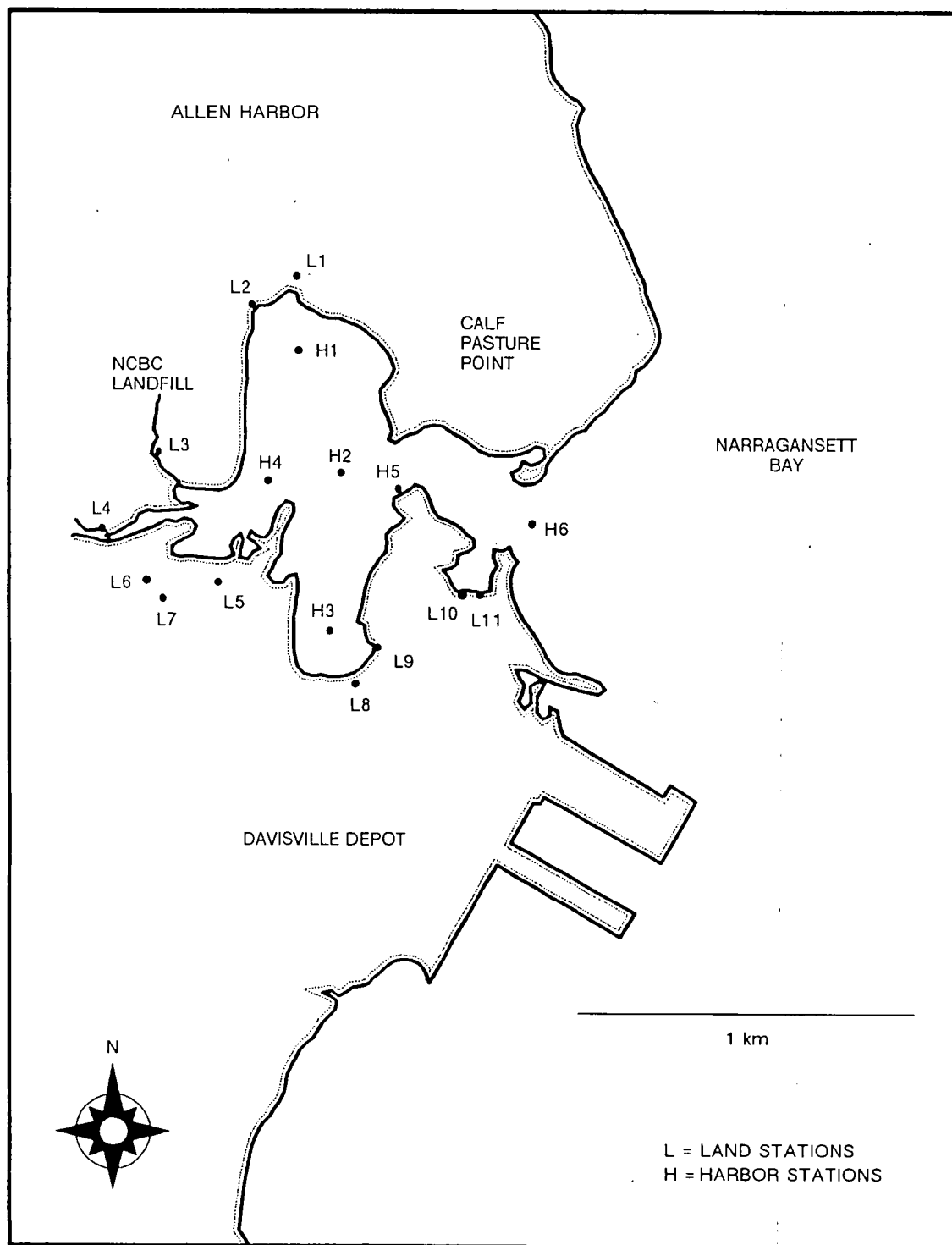
Figure C-1. Locations of sanitary survey sampling stations.

These stations were designated L1 through L11. Stations L1-L4 are fresh water flows, L5 is a marsh drainage, L7 is an oil separator drainage, and L6, L8, L9, L10, and L11 are storm drains. Flow measurements using velocity-cross section methods were made at the fresh water inputs (Figure C-1). Six harbor stations were examined to determine harbor water quality. These stations were designated H1 through H6.

Sample Collection

Sampling was conducted during two periods in 1989: an eight-day summer period from 31 July to 7 August, and a five-day fall period from 30 October to 3 November. All land and harbor samples were collected from the water surface using sterile 1-L polypropylene bottles. Harbor station water samples were collected at both high and low tides. Samples were refrigerated or stored on ice until assayed. All samples were examined within 30 hours of collection.

In addition to the large scale surveys, surface and bottom water samples were collected weekly at station H5. These samples were used to determine water quality at the entrance of the harbor.

Rainfall was recorded during each sampling period. Rainfall increases both land station flow and surface runoff into the harbor, thereby influencing harbor water quality. Salinities were measured during sample collection to determine if fresh water inputs influenced salinity in the harbor.

Laboratory Procedures

Enterococci--

Culture medium for the mF method was prepared by bringing 1000 ml of deionized water (DI) and 71.2 g of mE Agar to a boil with constant stirring, and autoclaving for 15 min at 121°C. The medium was cooled to 45°C and 0.24 g of nalidixic acid dissolved in 0.3 ml sterile water, 0.2 ml of a 10N sodium hydroxide solution, 0.2 g of 2,3,5 triphenyltetrazolium chloride and 0.75 g of indoxyl-B-D-glucoside dissolved in 5.0 ml of 95% ethanol and 5.0 ml of sterile water were added. Media was dispensed in 4.5-ml aliquots into 9X50-mm petri dishes and allowed to solidify. Water samples were added to a pre-sterilized filter holder loaded with a sterile 0.45-μm membrane. A vacuum was applied to draw the sample through and each membrane was rinsed with phosphate buffered saline.

The membrane was removed from the holder and placed on an mE agar plate. Plates were inverted and incubated for 48 hr at 41°C. Positive results were determined by the presence of colonies with pink centers, gray fringes and blue halos.

To determine the presence of enterococci by the MPN method, 10-ml aliquots of single strength (34.7 g/1000 ml DI) or double strength (69.4 g/1000 ml DI) Azide Dextrose Broth were dispensed into 16X150 and 20X150-mm test tubes, respectively, and autoclaved at 116°C for 10 min. Five double strength tubes were inoculated with 10 ml of sample, five single strength tubes were inoculated with 1 ml of sample, and five single strength tubes were inoculated with 1 ml of a -1 (one tenth) dilution of the sample. Tubes were incubated for 24 hr at 35°C and scored for growth, which was detected as turbidity. Confirmation tests were performed on all positive samples by transferring bacteria to a 0.45-μm membrane placed on an mE plate. Plates were incubated for 48 hr at 44.5°C. Positive results were detected as blue colonies with pink centers and gray fringes.

Fecal coliform (*Escherichia coli*)--

Fecal coliforms were enumerated by the mF method by bringing 45.3 g of dehydrated mTEC Agar and 1000 ml DI water to a boil and autoclaving at 121°C for 15 minutes. Cooled medium was dispensed in 4.5-ml aliquots into 9X50-mm petri dishes and allowed to solidify. Water samples were added to a pre-sterilized filter holder loaded with a sterile 0.45-μm membrane. A vacuum was applied to draw the sample through, and each membrane was rinsed with phosphate buffered saline. The membrane was removed from the holder and placed on an mTEC plate. The plates were incubated in styrofoam blocks at 44°C for 20 hr. The presence of fecal coliforms was indicated by yellow colonies. The membranes were transferred for 20 min to filter pads saturated with a urea substrate containing 2.0 g of urea, 0.01 g phenol red, and 100 ml of water (pH adjusted to 5.0 with hydrochloric acid). Colonies able to maintain their yellow color were indicative of *Escherichia coli*.

To enumerate fecal coliforms by the MPN tube method, 10-ml aliquots of single (35.6 g/1000 ml DI) and double strength (71.2 g/1000 ml DI) Lauryl Tryptose Broth were dispensed into 16X150 and 20X150-mm test tubes containing inverted 6X50-mm culture tubes, respectively. Media was then autoclaved at 121°C for 15 min. Five double strength tubes were inoculated with 10 ml of sample, five single strength tubes were inoculated with 1 ml of sample, and five single strength tubes were inoculated with 1 ml of a -1 dilution of the sample. All tubes were incubated at 35°C. At 24 and 48 hr, tubes were examined for gas production which was indicative of fecal coliform presence. Confirmation tests of

positive tubes were conducted using EC MUG medium containing 37.0 g of EC medium, 0.05 g 4-methylumbelliferyl-B-D-glucuronide, and 1000 ml DI water. The medium was dispensed in 5-ml aliquots into 6X50-mm tubes containing inverted 6X50-mm culture tubes, and autoclaved at 121°C for 15 min. Confirmation tests were conducted by transferring bacteria to EC MUG tubes and incubating for 24 hr at 44.5°C. Tubes were examined for gas production and fluorescence. Fecal coliforms were indicated by the presence of gas and *Escherichia coli* were detected by the presence of gas and fluorescence.

Clostridium perfringens--

To enumerate *Clostridium perfringens* by the membrane filtration method, 30.0 g of tryptose, 20.0 g of yeast extract, 5.0 g of sucrose, 1.0 g of L-cysteine hydrochloride, and 0.04 g bromocresol purple were dissolved in 980 ml DI water. The pH was adjusted to 7.6 with 10N sodium hydroxide, and 15.0 g Bacto agar was added. The medium was boiled to dissolve the agar, autoclaved at 121°C for 15 min, and cooled to 45°C. Twenty ml of 0.5% phenolphthalein diphosphate solution, 0.4 g of d-cycloserine, 0.025 g polmyxin b sulfate, and 2.0 ml of a 4.5% ferric chloride solution then was added to the medium. The medium was mixed and then dispensed in 4.5-ml aliquots into 9X50-mm petri dishes and allowed to solidify. Samples were added to a pre-sterilized filter holder loaded with a sterile 0.45-μm membrane. A vacuum was applied to draw the sample through and each membrane was rinsed with phosphate buffered saline. The membrane was removed from the holder and placed on an mCP agar plate. Plates were incubated anaerobically for 18-24 hr at 44.5-45°C. Yellow, large flat colonies were scored and plates were inverted over ammonium hydroxide for 20-30 sec. The presence of magenta colonies were indicative of *Clostridium perfringens*.

To determine the presence of *Clostridium perfringens* by the MPN method, 10 ml of homogenized milk was dispensed into 16X150-mm test tubes containing 0.2 g of iron filings and then autoclaved at 116°C for 10 min. Five tubes were inoculated with 10 ml of sample, five tubes with 1 ml of sample, and five tubes with 1 ml of a -1 dilution of the sample. Tubes were incubated for 18 hr at 45°C. Positive results were determined as stormy fermentation of the medium.

RESULTS AND DISCUSSION

Emphasis in the following discussion focuses upon fecal coliform levels as

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TABLE C-1. FRESH WATER FLOW MEASUREMENTS AND RELATIVE FECAL COLIFORM LOADINGS

Station	Date	Flow (cfs)	Fecal Coliform CFU[1]/100ml	Fecal Coliforms/sec
L1	07/31	0.07	590	1.2×10^4
	11/01	0.63	5200	9.3×10^5
L2	07/31	0.04	70	7.9×10^2
	11/01	0.42	160	1.9×10^4
L3	07/31	0.03	28	2.4×10^2
	11/01	<0.10	130	3.7×10^3
	11/03	0.21	250	1.5×10^4
L4	07/31	1.10	270	8.4×10^4
	08/04	1.20	660	2.2×10^5
	08/06	3.30	1760	1.6×10^6
	10/31	2.60	310	2.3×10^5
	11/01	7.90	3500	7.8×10^6
	11/02	4.40	400	5.0×10^5
	11/03	5.80	420	6.9×10^5
L5	07/31	0.01	240	1.6×10^3
	08/06	0.17	1170	5.6×10^4
	10/30	0.09	15	3.8×10^2
	11/01	0.47	300	4.0×10^4
	11/02	0.29	60	4.9×10^3
	11/03	1.00	200	5.7×10^4
L6	07/31	<0.01	470	$<1.3 \times 10^3$
	08/04	0.01	20	5.7×10^1
	08/06	0.15	>800	$>3.4 \times 10^4$
	10/30	0.04	17	1.9×10^2
	11/01	0.08	510	1.2×10^4
	11/02	0.06	80	1.4×10^3
	11/03	0.12	250	8.5×10^3
L7	08/04	0.01	122	3.5×10^2
	08/06	0.03	200	1.7×10^3
	11/03	0.03	170	1.4×10^3
L8	08/06	0.30	>800	$>6.8 \times 10^4$
	11/03	0.05	230	3.3×10^3
L9	08/06	0.30	30	2.6×10^3
	11/03	0.03	100	8.5×10^2
L10	08/06	0.02	420	2.4×10^3
	11/03	0.03	150	1.3×10^3
L11	11/03	0.02	250	1.4×10^3

[1] colony forming units

determined by the most probable number (MPN) and membrane filtration (mF) methods.

All data obtained as part of these surveys are provided in the attached listings.

All 11 land stations exhibited consistently high levels of fecal coliforms during the summer sampling period. Land station flow measurements and relative fecal coliform loadings for this period are shown in Table C-1. Dry weather conditions prevailed with only 0.10 inches of rainfall and low fresh water inputs. As expected, no significant differences were noted between the harbor station surface and bottom water salinities (Table C-2). Boating activity, as observed on 6 and 7 August, may have contributed to elevated fecal coliform counts at the harbor stations. Approximately 0.69 in of rainfall on 6 and 7 August resulted in increased fresh water flow which may have contributed to elevated fecal coliform counts.

TABLE C-2. SURFACE AND BOTTOM WATER SALINITIES FOR THE SUMMER SURVEY

Station	Tide	Average surface salinity (ppt)	Average bottom salinity (ppt)
H1	H	30.1	28.7
	L	30.2	31.0
H2	H	30.4	28.5
	L	30.1	30.7
H3	H	28.7	30.9
	L	30.4	30.9
H4	L	30.1	nm[1]
H5	L	30.4	30.4
H6	H	30.8	31.0
	L	30.6	30.7

[1] nm = not measured

During the fall survey, relative fecal coliform loadings from the land stations increased by over an order of magnitude after rainfall events (Table C-1). The largest contribution occurred at station L4, with somewhat smaller inputs from station L1.

Harbor stations H1, H2, H4, H5 and H6 exceeded NSSP standards for low tide samples during the summer survey period (Table C-3). Station H3 exceeded NSSP standards during both high and low tides. All six harbor stations failed to meet NSSP standards during the fall survey, as indicated from low and high tide samples. Approximately 2.0 in of rain fell during this period, decreasing surface salinities relative to both bottom (Table C-4) and summer conditions (see Table C-2).

Samples collected at station H5 reflected water quality at the entrance of the harbor. Overall, this station displayed increased levels of fecal coliforms after weekends, when increased boating activity may have contributed to fecal contamination. Elevated levels were

TABLE 6. GEOMETRIC MEAN FECAL COLIFORM DENSITIES AND 19TH PERCENTILE FECAL COLIFORM DENSITIES FOR HIGH AND LOW TIDES DURING THE SUMMER AND FALL SURVEYS[1]

Station	Tide	Geometric mean fecal coliform density/100 ml		90th percentile fecal coliform density/100 ml	
		Summer	Fall	Summer	Fall
H1	H	7.3	216.7	21.0	920.0
	L	13.9	230.5	79.0	540.0
H2	H	9.4	67.7	17.0	350.0
	L	15.2	121.9	110.0	1600.0
H3	H	3.8	200.1	7.8	920.0
	L	5.2	39.7	17.0	350.0
H4	L	57.3	156.0	540.0	240.0
H5	L	19.5	43.4	70.0	350.0
H6	H	4.5	154.3	17.0	1600.0
	L	11.1	73.0	170.0	240.0

[1] Densities determined using the most probable number (MPN) method.

also observed after rainfall events, indicating the influences of fresh water land and runoff sources.

This evaluation revealed the potential of several fresh water land inputs which contribute to the poor water quality in Allen Harbor. The largest fresh water inputs of fecal coliforms were from the stations L4 and L1 following rainfall events. Fecal coliform loadings were observed to increase by over an order of magnitude following significant rain. Input from the established fresh water pollution sources, runoff, and boating activity all contributed to the poor water quality observed at the harbor stations.

TABLE C-4. SURFACE AND BOTTOM WATER SALINITIES FOR THE FALL SURVEY

Station	Tide	Average surface salinity (ppt)	Average bottom salinity (ppt)
H1	H	26.2	28.1
	L	24.7	28.0
H2	H	26.3	28.0
	L	25.8	28.3
H3	H	24.5	29.0
	L	25.7	28.8
H4	L	25.2	nm[1]
H5	L	25.1	27.4
H6	H	26.6	29.0
	L	26.6	28.4

[1] nm = not measured

LISTING C-I. SUMMER AND FALL SANITARY SURVEY DATA

EXPLANATION: The following table is a listing of all data collected during the summer and fall sanitary surveys of Allen Harbor. Translation of column-wise variable names is as follows:

Record #	= an internal record number
TIME	= time of sample collection
TIDE	= tidal condition
STA	= station
FC	= MPN fecal coliforms
EC	= MPN *E. coli*
FSTREP	= MPN Enterococci
MTECH	= mF fecal coliforms
MEC	= mF *E. coli*
ENT	= mF Enterococci
CLPR	= MPN *C. perfringens*
MCP	= mF *C. perfringens*
TSAL	= surface water salinity (ppt)
TTEMP	= surface water temperature (°C)
BSAL	= bottom water salinity (ppt)
BTEMP	= bottom water temperature (°C)
LABNO	= laboratory sample number
COMMENTS	= comment field
REALDATE	= date of sample collection

Record#	TIME	TIDE	STA	FC	FC	FSTREP	MTECH	HEC	ENT	CLPR	HCP	TSAL	TTEMP	BSAL	BTEMP	LABNO	COMMENTS	REALDATE
1	.			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0		/ /
2	.			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0		/ /
3	.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0		/ /
4	0830	H	H1	6.8	4.0	1.9	4.0	4.0	1.9	1.9	0.9	30.1	23.4	30.1	22.6	1		07/31/89
5	0929	H	H1	21.0	11.0	1.9	14.0	14.0	0.9	2.0	0.9	30.1	23.8	30.1	22.9	35		08/02/89
6	1052	H	H1	4.5	4.5	2.0	5.0	4.0	0.9	1.9	0.9	30.1	25.0	30.8	24.8	57		08/04/89
7	1234	H	H1	4.5	2.0	1.9	4.0	4.0	0.9	1.9	0.9	30.0	25.6	31.4	23.9	82		08/06/89
8	0843	H	H1	79.0	13.0	7.8	11.0	11.0	5.0	2.0	5.0	25.4	15.2	27.7	13.9	1		10/30/89
9	0930	H	H1	920.0	540.0	33.0	220.0	210.0	57.0	2.0	5.0	26.5	15.0	28.3	14.4	30		11/01/89
10	1055	H	H1	33.0	33.0	13.0	92.0	92.0	5.0	9.3	2.0	26.7	13.3	28.6	13.7	46		11/02/89
11	1039	H	H1	920.0	920.0	240.0	520.0	500.0	420.0	240.0	3.0	26.3	12.6	28.3	13.8	60		11/03/89
12	1510	L	H1	6.8	6.8	1.9	5.0	5.0	0.9	1.9	0.9	29.8	26.3	29.6	23.8	5		07/31/89
13	1450	L	H1	7.8	7.8	1.9	3.0	3.0	0.9	2.0	1.0	30.4	24.1	30.6	23.1	23		08/01/89
14	1500	L	H1	7.8	7.8	1.9	10.0	10.0	0.9	1.9	0.9	29.4	25.1	30.2	23.4	39		08/02/89
15	1556	L	H1	7.8	7.8	4.5	12.0	12.0	0.9	1.9	0.9	30.9	26.9	32.3	24.0	64		08/04/89
16	1609	L	H1	23.0	23.0	1.9	19.0	19.0	0.9	1.9	0.9	30.5	26.3	31.4	23.5	70		08/05/89
17	1615	L	H1	17.0	13.0	2.0	5.0	4.0	0.9	1.9	0.9	30.2	27.0	31.8	24.3	86		08/06/89
18	0516	L	H1	79.0	79.0	17.0	29.0	27.0	9.0	23.0	0.9	30.5	24.7	31.3	24.5	93		08/07/89
19	1334	L	H1	130.0	49.0	79.0	80.0	80.0	20.0	1.9	2.0	24.6	15.6	27.7	14.1	5		10/30/89
20	1340	L	H1	49.0	49.0	49.0	112.0	111.0	24.0	130.0	0.9	22.9	15.4	27.8	14.3	23		10/31/89
21	1436	L	H1	540.0	540.0	130.0	510.0	500.0	51.0	1.8	7.0	25.8	15.5	28.8	14.6	40		11/01/89
22	1437	L	H1	540.0	540.0	49.0	240.0	210.0	69.0	23.0	1.0	24.1	13.5	28.8	13.9	50		11/02/89
23	1604	L	H1	350.0	350.0	240.0	400.0	380.0	250.0	49.0	11.0	25.9	12.2	27.3	13.8	68		11/03/89
24	1108		H1SED	19.9	19.9	19.9	0.0	0.0	0.0	920000.0	0.0	0.0	0.0	0.0	0.0	17		08/01/89
25	1145		H1SED	110.0	68.0	230.0	0.0	0.0	0.0	350000.0	0.0	0.0	0.0	0.0	0.0	51		08/03/89
26	0950		H1SED	9200.0	1100.0	330.0	0.0	0.0	0.0	46000.0	0.0	0.0	0.0	0.0	0.0	20		10/31/89
27	1038		H1SHE	18.0	18.0	45.0	0.0	0.0	0.0	330.0	0.0	0.0	0.0	0.0	0.0	20		08/01/89
28	1145		H1SHE	20.0	20.0	19.9	0.0	0.0	0.0	230.0	0.0	0.0	0.0	0.0	0.0	54		08/03/89
29	0947		H1SHE	5400.0	330.0	110.0	0.0	0.0	0.0	2400.0	0.0	0.0	0.0	0.0	0.0	17		10/31/89
30	0825	H	H2	13.0	7.8	1.9	9.0	9.0	0.9	1.9	0.9	29.7	23.1	29.2	22.4	2		07/31/89
31	0927	H	H2	7.8	4.5	1.9	5.0	5.0	0.9	1.9	0.9	30.0	23.7	30.4	22.6	36		08/02/89
32	1044	H	H2	4.5	4.5	1.9	9.0	9.0	0.9	1.9	0.9	30.9	24.2	31.0	22.9	58		08/04/89
33	1231	H	H2	17.0	17.0	1.9	13.0	13.0	0.9	1.9	0.9	31.0	24.8	31.2	23.2	83		08/06/89
34	0838	H	H2	13.0	13.0	7.8	22.0	21.0	8.0	1.8	3.0	26.4	14.1	27.7	13.8	2		10/30/89
35	0922	H	H2	350.0	350.0	130.0	540.0	500.0	170.0	2.0	8.0	26.1	14.7	27.9	14.6	31		11/01/89
36	1047	H	H2	140.0	140.0	23.0	170.0	160.0	12.0	13.0	9.0	26.6	13.3	29.1	14.4	47		11/02/89
37	1034	H	H2	33.0	33.0	7.8	44.0	43.0	11.0	23.0	1.0	26.0	12.4	27.8	13.4	61		11/03/89
38	1510	L	H2	2.0	2.0	1.9	2.0	2.0	0.9	1.9	0.9	29.7	25.5	30.3	22.9	6		07/31/89
39	1436	L	H2	49.0	49.0	1.9	21.0	20.0	0.9	540.0	9.9	30.6	24.3	30.4	24.3	24		08/01/89
40	1446	L	H2	4.5	4.5	1.9	5.0	5.0	0.9	2.0	0.9	30.1	24.6	30.1	23.7	40		08/02/89
41	1547	L	H2	14.0	14.0	4.0	12.0	12.0	0.9	1.9	0.9	28.8	25.6	31.1	23.3	65		08/04/89
42	1600	L	H2	70.0	110.0	17.0	89.0	80.0	0.9	1.9	0.9	30.2	25.2	30.5	23.5	71		08/05/89
43	1608	L	H2	4.0	4.0	1.9	2.0	2.0	0.9	1.9	0.9	31.1	25.4	31.5	23.3	87		08/06/89
44	0514	L	H2	110.0	110.0	13.0	51.0	50.0	21.0	23.0	0.9	30.2	24.7	31.3	23.9	94		08/07/89
45	1326	L	H2	11.0	11.0	7.8	4.0	4.0	0.9	2.0	5.0	25.8	15.7	27.5	14.1	6		10/30/89
46	1332	L	H2	49.0	21.0	23.0	31.0	31.0	-8.0	23.0	2.0	26.0	15.3	27.8	14.4	24		10/31/89
47	1427	L	H2	1600.0	540.0	240.0	440.0	420.0	260.0	34.0	13.0	25.2	15.5	27.7	14.7	41		11/01/89
48	1430	L	H2	130.0	34.0	7.8	59.0	59.0	5.0	23.0	4.0	26.6	13.6	31.1	14.2	51		11/02/89
49	1550	L	H2	240.0	240.0	130.0	100.0	90.0	130.0	33.0	4.0	25.6	12.1	27.8	13.4	69		11/03/89
50	1102		H2SED	19.9	19.9	19.9	0.0	0.0	0.0	540000.0	0.0	0.0	0.0	0.0	0.0	18		08/01/89
51	1125		H2SED	140.0	140.0	490.0	0.0	0.0	0.0	540000.0	0.0	0.0	0.0	0.0	0.0	52		08/03/89
52	0931		H2SED	3500.0	2400.0	790.0	0.0	0.0	0.0	140000.0	0.0	0.0	0.0	0.0	0.0	22		10/31/89
53	1031		H2SHE	20.0	20.0	20.0	0.0	0.0	0.0	330.0	0.0	0.0	0.0	0.0	0.0	21		08/01/89
54	1130		H2SHE	20.0	20.0	19.9	0.0	0.0	0.0	330.0	0.0	0.0	0.0	0.0	0.0	55		08/03/89
55	0927		H2SHE	230.0	19.9	20.0	0.0	0.0	0.0	490.0	0.0	26.1	15.1	28.6	14.3	18		10/31/89
56	0820	H	H3	7.8	7.8	1.9	0.9	0.9	0.9	1.9	0.9	29.9	23.1	30.7	22.7	3		07/31/89
57	0920	H	H3	2.0	2.0	1.9	0.9	0.9	0.9	1.9	0.9	30.1	24.3	30.5	22.3	37		08/02/89
58	1044	H	H3	1.9	1.9	1.9	2.0	2.0	1.0	1.9	0.9	30.8	23.8	31.0	23.0	59		08/04/89
59	1227	H	H3	6.8	6.8	1.9	2.0	2.0	0.9	1.9	0.9	31.1	24.2	31.3	23.1	84		08/06/89

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#	Time		Type														
60	0824	H	H3	33.0	1.8	2.0	0.9	0.9	0.9	1.9	6.0	25.6	15.4	27.8	14.3	3	10/30/89
61	0920	H	H3	920.0	920.0	240.0	670.0	590.0	90.0	2.0	12.0	25.0	14.7	28.6	14.3	32	11/01/89
62	1045	H	H3	220.0	220.0	17.0	160.0	140.0	22.0	23.0	5.0	24.2	12.0	30.5	13.8	48	11/02/89
63	1029	H	H3	240.0	240.0	1.9	106.0	104.0	22.0	240.0	2.0	21.2	11.0	29.2	14.1	62	11/03/89
64	1454	L	H3	1.9	1.9	1.9	0.9	0.9	0.9	1.9	0.9	30.0	24.3	30.4	22.3	7	07/31/89
65	1432	L	H3	17.0	17.0	1.9	12.0	12.0	0.9	2.0	0.9	29.1	24.5	30.7	23.0	25	08/01/89
66	1420	L	H3	1.9	1.9	1.9	0.9	0.9	0.9	2.0	0.9	30.0	24.3	30.2	22.9	41	08/02/89
67	1541	L	H3	6.8	6.8	1.9	3.0	3.0	0.9	1.9	0.9	30.8	24.7	30.8	22.8	66	08/04/89
68	1556	L	H3	6.8	6.8	11.0	3.0	3.0	2.0	1.9	0.9	30.8	24.4	31.2	23.2	72	08/05/89
69	1558	L	H3	7.8	7.8	1.9	1.0	1.0	0.9	1.9	0.9	31.1	24.6	31.7	24.7	88	08/06/89
70	0508	L	H3	4.5	4.5	4.5	2.0	2.0	3.0	1.9	0.9	30.9	23.8	31.0	23.1	95	08/07/89
71	1320	L	H3	4.5	1.9	1.9	2.0	2.0	0.9	2.0	4.0	27.0	14.3	27.7	13.9	7	10/30/89
72	1326	L	H3	2.0	2.0	2.0	1.0	1.0	4.0	7.8	1.0	27.0	14.5	29.9	13.6	25	10/31/89
73	1419	L	H3	350.0	350.0	240.0	630.0	590.0	2.0	6.8	10.0	26.5	15.5	28.2	14.5	42	11/01/89
74	1425	L	H3	240.0	240.0	13.0	90.0	88.0	1.0	2.0	5.0	26.6	15.0	29.9	14.5	52	11/02/89
75	1543	L	H3	130.0	130.0	79.0	80.0	80.0	60.0	23.0	7.0	21.6	10.6	29.1	14.0	70	11/03/89
76	1055		H3SED	19.9	19.9	19.9	0.0	0.0	0.0	1600000.0	0.0	0.0	0.0	0.0	0.0	19	08/01/89
77	1145		H3SED	20.0	20.0	45.0	0.0	0.0	0.0	920000.0	0.0	0.0	0.0	0.0	0.0	53	08/03/89
78	0924		H3SED	3500.0	330.0	170.0	0.0	0.0	0.0	49000.0	0.0	0.0	0.0	0.0	0.0	21	10/31/89
79	1015		H3SHE	19.9	19.9	45.0	0.0	0.0	0.0	230.0	0.0	0.0	0.0	0.0	0.0	22	08/01/89
80	1125		H3SHE	19.9	19.9	45.0	0.0	0.0	0.0	330.0	0.0	0.0	0.0	0.0	0.0	56	08/03/89
81	0912		H3SHE	9200.0	230.0	170.0	0.0	0.0	0.0	2400.0	0.0	27.1	14.9	28.5	14.3	19	10/31/89
82	1518	L	H4	7.8	7.8	1.9	4.0	4.0	0.9	1.9	0.9	30.0	25.8	0.0	0.0	8	07/31/89
83	1503	L	H4	70.0	70.0	1.9	21.0	21.0	0.9	4.5	5.0	28.3	25.4	0.0	0.0	26	08/01/89
84	1455	L	H4	4.5	4.5	1.9	5.0	5.0	0.9	2.0	0.9	30.3	25.2	0.0	0.0	42	08/02/89
85	1554	L	H4	240.0	240.0	49.0	140.0	137.0	1.0	6.8	0.9	30.4	25.9	0.0	0.0	67	08/04/89
86	1605	L	H4	49.0	33.0	13.0	34.0	32.0	1.0	1.9	0.9	31.3	25.0	0.0	0.0	73	08/05/89
87	1612	L	H4	540.0	540.0	79.0	570.0	450.0	360.0	4.5	0.9	30.7	25.7	0.0	0.0	89	08/06/89
88	0520	L	H4	130.0	130.0	49.0	126.0	126.0	78.0	23.0	0.9	29.5	27.1	0.0	0.0	96	08/07/89
89	1331	L	H4	130.0	33.0	7.8	9.0	8.0	0.9	1.9	5.0	25.1	16.6	0.0	0.0	8	10/30/89
90	1338	L	H4	130.0	110.0	23.0	65.0	62.0	38.0	49.0	2.0	26.1	15.4	0.0	0.0	26	10/31/89
91	1429	L	H4	240.0	240.0	49.0	310.0	270.0	55.0	11.0	15.0	26.1	15.4	0.0	0.0	43	11/01/89
92	1432	L	H4	95.0	49.0	130.0	90.0	90.0	56.0	23.0	6.0	24.6	14.1	0.0	0.0	53	11/02/89
93	1558	L	H4	240.0	240.0	79.0	75.0	75.0	75.0	49.0	3.0	25.1	12.3	0.0	0.0	71	11/03/89
94	1404	L	H5	7.8	4.5	1.9	6.0	6.0	1.0	1.9	0.9	29.5	25.0	29.3	24.9	9	07/31/89
95	1526	L	H5	33.0	33.0	1.9	22.0	21.0	0.9	1.9	0.9	30.5	24.1	30.5	23.8	27	08/01/89
96	1513	L	H5	12.0	6.8	1.9	1.0	1.0	0.9	1.9	0.9	30.1	24.5	30.4	24.0	43	08/02/89
97	1608	L	H5	4.5	1.9	1.9	2.0	2.0	0.9	2.0	0.9	31.0	25.0	31.0	24.2	68	08/04/89
98	1621	L	H5	70.0	70.0	2.0	29.0	24.0	0.9	1.9	0.9	30.6	25.2	30.6	24.5	74	08/05/89
99	1630	L	H5	33.0	17.0	4.5	13.0	10.0	0.9	1.9	0.9	31.2	24.8	31.3	24.8	90	08/06/89
100	0534	L	H5	33.0	33.0	27.0	28.0	27.0	17.0	23.0	0.9	29.8	26.6	29.7	26.7	97	08/07/89
101	1350	L	H5	23.0	2.0	1.9	3.0	3.0	1.0	1.9	3.0	26.1	16.1	27.5	14.4	9	10/30/89
102	1355	L	H5	17.0	17.0	1.9	17.0	17.0	0.9	4.5	3.0	26.6	14.9	27.7	14.4	27	10/31/89
103	1450	L	H5	49.0	49.0	130.0	400.0	370.0	42.0	2.0	10.0	25.1	15.4	27.9	14.7	44	11/01/89
104	1450	L	H5	350.0	110.0	13.0	90.0	90.0	1.0	4.5	5.0	0.0	13.8	0.0	14.3	54	11/02/89
105	1538	L	H5	23.0	23.0	23.0	140.0	130.0	120.0	49.0	8.0	22.4	11.4	27.1	13.3	72	11/03/89
106	0838	H	H6	6.8	4.0	2.0	5.0	4.0	0.9	1.9	0.9	30.1	22.7	30.4	21.8	4	07/31/89
107	0937	H	H6	1.9	1.9	1.9	0.9	0.9	0.9	2.0	0.9	30.2	22.4	30.6	22.1	38	08/02/89
108	1100	H	H6	1.9	1.9	1.9	0.9	0.9	0.9	2.0	0.9	31.0	23.4	31.0	22.7	60	08/04/89
109	1242	H	H6	17.0	4.0	4.5	10.0	9.0	0.9	1.9	0.9	32.0	24.0	31.9	23.0	85	08/06/89
110	0844	H	H6	79.0	49.0	17.0	42.0	20.0	10.0	2.0	8.0	27.7	13.9	28.9	13.9	4	10/30/89
111	0935	H	H6	1600.0	1600.0	240.0	760.0	670.0	750.0	4.5	9.0	26.5	14.5	29.6	14.4	33	11/01/89
112	1100	H	H6	64.0	64.0	33.0	19.0	18.0	1.0	23.0	6.0	26.4	13.1	29.1	13.8	49	11/02/89
113	1044	H	H6	70.0	46.0	130.0	36.0	33.0	3.0	49.0	3.0	25.9	12.3	28.5	13.8	63	11/03/89
114	1523	L	H6	1.9	1.9	1.9	0.9	0.9	0.9	1.9	0.9	30.6	24.9	30.7	25.1	10	07/31/89
115	1520	L	H6	170.0	22.0	1.9	23.0	22.0	0.9	130.0	9.9	29.9	24.8	30.3	24.1	28	08/01/89
116	1505	L	H6	4.5	1.9	1.9	3.0	3.0	0.9	2.0	0.9	30.2	25.3	30.2	23.5	44	08/02/89
117	1406	L	H6	4.5	2.0	1.9	1.0	1.0	1.0	1.9	0.9	31.3	25.3	32.0	23.4	69	08/04/89
118	1614	L	H6	7.8	7.8	2.0	14.0	14.0	0.9	1.9	0.9	31.0	24.8	30.9	23.6	75	08/05/89
119	1624	L	H6	12.0	6.8	1.9	2.0	1.0	0.9	1.9	0.9	31.1	25.2	31.2	25.2	91	08/06/89
120	0529	L	H6	33.0	33.0	13.0	12.0	9.0	3.0	1.9	0.9	29.8	26.3	29.8	26.0	98	08/07/89
121	1345	L	H6	23.0	4.0	1.9	4.9	4.9	4.9	1.9	5.0	27.7	15.4	27.2	14.8	10	10/30/89
122	1350	L	H6	17.0	11.0	2.0	8.0	8.0	8.0	13.0	7.0	26.8	14.8	27.6	14.3	28	10/31/89
123	1445	L	H6	240.0	240.0	130.0	320.0	320.0	54.0	1.9	6.0	26.4	15.1	30.3	14.5	45	11/01/89
124	1449	L	H6	130.0	130.0	4.5	35.0	15.0	1.0	11.0	9.9	27.0	13.7	29.0	14.2	55	11/02/89

125	1607 L	H6	170.0	170.0	150.0	110.0	100.0	47.0	23.0	4.0	25.1	12.1	27.9	13.8	73	11/03/89
126	1011	L1	0.0	0.0	0.0	590.0	480.0	10.0	0.0	0.9	0.0	0.0	0.0	0.0	11	07/31/89
127	1240	L1	0.0	0.0	0.0	20.0	20.0	30.0	0.0	9.9	0.0	24.0	0.0	0.0	29	08/01/89
128	1226	L1	0.0	0.0	0.0	19.0	19.0	20.0	0.0	0.9	0.0	24.0	0.0	0.0	45	08/02/89
129	1455	L1	0.0	0.0	0.0	11.0	11.0	10.0	0.0	10.0	0.0	15.0	0.0	0.0	11	10/30/89
130	1215	L1	0.0	0.0	0.0	5200.0	4800.0	280.0	0.0	50.0	0.0	15.6	0.0	0.0	34	11/01/89
131	1548	L1	0.0	0.0	0.0	370.0	360.0	70.0	0.0	40.0	0.0	0.0	0.0	0.0	74	11/03/89
132	1044	L10	0.0	0.0	0.0	420.0	420.0	10.0	0.0	0.9	0.0	27.0	0.0	0.0	81	08/06/89
133	0948	L10	0.0	0.0	0.0	150.0	140.0	500.0	0.0	9.9	0.0	0.0	0.0	0.0	66	11/03/89
134	1011	L12	0.0	0.0	0.0	110.0	110.0	750.0	0.0	10.0	0.0	0.0	0.0	0.0	67	11/03/89
135	1030	L2	0.0	0.0	0.0	70.0	70.0	83.0	0.0	0.9	0.0	0.0	0.0	0.0	12	07/31/89
136	1252	L2	0.0	0.0	0.0	190.0	190.0	54.0	0.0	0.9	0.0	18.0	0.0	0.0	30	08/01/89
137	1233	L2	0.0	0.0	0.0	180.0	180.0	150.0	0.0	0.9	0.0	18.0	0.0	0.0	46	08/02/89
138	1500	L2	0.0	0.0	0.0	77.0	77.0	26.0	0.0	17.0	0.0	13.3	0.0	0.0	12	10/30/89
139	1229	L2	0.0	0.0	0.0	160.0	160.0	20.0	0.0	10.0	0.0	15.0	0.0	0.0	35	11/01/89
140	1543	L2	0.0	0.0	0.0	250.0	250.0	160.0	0.0	9.9	0.0	0.0	0.0	0.0	75	11/03/89
141	1044	L3	0.0	0.0	0.0	28.0	28.0	140.0	0.0	0.9	0.0	0.0	0.0	0.0	13	07/31/89
142	1253	L3	0.0	0.0	0.0	20.0	20.0	51.0	0.0	9.9	0.0	20.0	0.0	0.0	31	08/01/89
143	1236	L3	0.0	0.0	0.0	20.0	20.0	68.0	0.0	0.9	0.0	20.0	0.0	0.0	47	08/02/89
144	1506	L3	0.0	0.0	0.0	19.0	18.0	2.0	0.0	2.0	0.0	13.3	0.0	0.0	13	10/30/89
145	1239	L3	0.0	0.0	0.0	130.0	120.0	20.0	0.0	20.0	0.0	13.9	0.0	0.0	36	11/01/89
146	1411	L3	0.0	0.0	0.0	20.0	20.0	80.0	0.0	10.0	0.0	11.7	0.0	0.0	56	11/02/89
147	1537	L3	0.0	0.0	0.0	250.0	240.0	90.0	0.0	9.9	0.0	0.0	0.0	0.0	76	11/03/89
148	1105	L4	0.0	0.0	0.0	270.0	260.0	170.0	0.0	9.9	0.0	0.0	0.0	0.0	14	07/31/89
149	1300	L4	0.0	0.0	0.0	110.0	110.0	90.0	0.0	9.9	0.0	22.0	0.0	0.0	32	08/01/89
150	1246	L4	0.0	0.0	0.0	290.0	290.0	240.0	0.0	0.9	0.0	22.0	0.0	0.0	48	08/02/89
151	1431	L4	0.0	0.0	0.0	660.0	660.0	740.0	0.0	0.9	0.0	24.0	0.0	0.0	61	08/04/89
152	1532	L4	0.0	0.0	0.0	1760.0	1530.0	800.1	0.0	9.9	0.0	24.0	0.0	0.0	92	08/06/89
153	1510	L4	0.0	0.0	0.0	300.0	300.0	310.0	0.0	39.0	0.0	14.4	0.0	0.0	14	10/30/89
154	1433	L4	0.0	0.0	0.0	310.0	300.0	220.0	0.0	70.0	0.0	13.9	0.0	0.0	29	10/31/89
155	1246	L4	0.0	0.0	0.0	3500.0	3400.0	1000.0	0.0	100.0	0.0	15.0	0.0	0.0	37	11/01/89
156	1400	L4	0.0	0.0	0.0	400.0	400.0	300.0	0.0	40.0	0.0	12.2	0.0	0.0	57	11/02/89
157	1532	L4	0.0	0.0	0.0	420.0	410.0	970.0	0.0	30.0	0.0	11.1	0.0	0.0	77	11/03/89
158	1150	L5	0.0	0.0	0.0	240.0	240.0	100.0	0.0	0.9	0.0	0.0	0.0	0.0	15	07/31/89
159	1317	L5	0.0	0.0	0.0	1010.0	1000.0	110.0	0.0	9.9	0.0	17.0	0.0	0.0	33	08/01/89
160	1302	L5	0.0	0.0	0.0	860.0	860.0	128.0	0.0	0.9	0.0	18.0	0.0	0.0	49	08/02/89
161	1122	L5	0.0	0.0	0.0	1170.0	1160.0	1980.0	0.0	0.9	0.0	18.0	0.0	0.0	76	08/06/89
162	1431	L5	0.0	0.0	0.0	15.0	15.0	2.0	0.0	2.0	0.0	0.0	0.0	0.0	15	10/30/89
163	1320	L5	0.0	0.0	0.0	300.0	300.0	160.0	0.0	20.0	0.0	13.3	0.0	0.0	38	11/01/89
164	1329	L5	0.0	0.0	0.0	60.0	60.0	30.0	0.0	20.0	0.0	11.7	0.0	0.0	58	11/02/89
165	1457	L5	0.0	0.0	0.0	200.0	170.0	220.0	0.0	40.0	0.0	0.0	0.0	0.0	79	11/03/89
166	1132	L6	0.0	0.0	0.0	470.0	270.0	26.0	0.0	0.9	0.0	0.0	0.0	0.0	16	07/31/89
167	1308	L6	0.0	0.0	0.0	360.0	330.0	22.0	0.0	0.9	0.0	17.0	0.0	0.0	34	08/01/89
168	1255	L6	0.0	0.0	0.0	23.0	23.0	40.0	0.0	0.9	0.0	17.0	0.0	0.0	50	08/02/89
169	1507	L6	0.0	0.0	0.0	20.0	20.0	33.0	0.0	0.9	0.0	17.0	0.0	0.0	62	08/04/89
170	1109	L6	0.0	0.0	0.0	800.1	800.1	800.1	0.0	0.9	0.0	22.0	0.0	0.0	77	08/06/89
171	1423	L6	0.0	0.0	0.0	17.0	17.0	-0.9	0.0	2.0	0.0	15.0	0.0	0.0	16	10/30/89
172	1305	L6	0.0	0.0	0.0	510.0	460.0	440.0	0.0	50.0	0.0	15.0	0.0	0.0	39	11/01/89
173	1318	L6	0.0	0.0	0.0	80.0	80.0	10.0	0.0	10.0	0.0	0.0	0.0	0.0	59	11/02/89
174	1440	L6	0.0	0.0	0.0	250.0	250.0	250.0	0.0	10.0	0.0	0.0	0.0	0.0	78	11/03/89
175	1500	L7	0.0	0.0	0.0	122.0	120.0	140.0	0.0	0.9	0.0	17.0	0.0	0.0	63	08/04/89
176	1103	L7	0.0	0.0	0.0	200.0	150.0	730.0	0.0	0.9	0.0	23.0	0.0	0.0	78	08/06/89
177	1436	L7	0.0	0.0	0.0	170.0	160.0	20.0	0.0	9.9	0.0	11.7	0.0	0.0	80	11/03/89
178	1019	L8	0.0	0.0	0.0	800.1	800.1	300.0	0.0	0.9	0.0	24.0	0.0	0.0	79	08/06/89
179	0925	L8	0.0	0.0	0.0	230.0	230.0	280.0	0.0	10.0	0.0	0.0	0.0	0.0	64	11/03/89
180	1033	L9	0.0	0.0	0.0	30.0	30.0	104.0	0.0	0.9	0.0	26.0	0.0	0.0	80	08/06/89
181	0934	L9	0.0	0.0	0.0	100.0	100.0	240.0	0.0	30.0	0.0	0.0	0.0	0.0	65	11/03/89
182	1515	SDCMP	0.0	0.0	0.0	70.0	70.0	190.0	0.0	10.0	2.0	12.8	0.0	0.0	81	11/03/89
183	1428	UNDBL	0.0	0.0	0.0	250.0	250.0	470.0	0.0	10.0	0.0	0.0	0.0	0.0	82	11/03/89

LISTING C-II.   WEEKLY SURVEY DATA FOR STATION H5

EXPLANATION: The following table is a listing of all data collected Allen Harbor station H5. Translation of column-wise variable names is as follows:

Record #	= an internal record number
SAMPLE_NO	= laboratory sample number
DATE	= date of sample collection
TIME	= time of sample collection
TEMP	= surface water temperature (°C)
MF_FC	= mF fecal coliforms
MF_EC	= mF *E. coli*
MF_CP	= mF *C. perfringens*
MF_EN	= mF Enterococci
PHAGE	= mF male specific bacteriophage

Record#	SAMPLE_NO	DATE	TIME	TEMP	MF_FC	MF_EC	MF_CP	MF_EN	PHAGE
1	001S	06/26/89	0835	19.9C	4.0	4.0	3.5	<1.0	<4.2
2	001B	06/26/89	0835	21.1C	2.5	2.5	2.0	1.0	<4.2
3	002S	07/05/89	1500	20.3C	<1.0	<1.0	4.5	<1.0	<4.2
4	002B	07/05/89	1500	20.8C	3.0	3.0	2.5	<1.0	<4.2
5	003S	07/12/89	0700	22.4C	8.0	8.0	3.0	1.0	<4.2
6	003B	07/12/89	0700	22.6C	5.5	5.5	2.5	1.5	<4.2
7	004S	07/17/89	1148	21.3C	835.0	830.0	6.5	136.5	16.8
8	004B	07/17/89	1148	21.6C	520.0	500.0	5.5	121.0	16.8
9	005S	07/19/89	1325	22.3C	70.0	70.0	13.5	4.5	<4.2
10	005B	07/19/89	1325	22.3C	45.0	45.0	9.5	4.0	<4.2
11	006S	07/24/89	1747	24.0C	45.0	45.0	11.5	4.0	<4.2
12	006B	07/24/89	1747	22.6C	27.5	27.5	9.5	1.5	<4.2
13	007S	08/01/89	1030	25.0C	6.0	6.0	<1.0	1.0	<4.2
14	007B	08/01/89	1030	ND	ND	ND	ND	ND	ND
15	008S	08/07/89	0530	26.6	29.0	28.5	<1.0	17.0	<4.2
16	008B	08/07/89	0530	ND	ND	ND	ND	ND	ND
17	009S	08/14/89	1032	24.4C	8.0	8.0	<1.0	<1.0	<4.2
18	009B	08/14/89	1032	23.3C	6.0	6.0	<1.0	1.0	<4.2
19	010S	08/21/89	1730	23.8C	14.0	13.0	<1.0	<1.0	<4.2
20	010B	08/21/89	1730	22.2C	<1.0	<1.0	<1.0	<1.0	<4.2
21	011S	08/29/89	1218	22.2C	1.0	1.0	6.0	1.0	<4.2
22	011B	08/29/89	1218	21.1C	1.0	1.0	18.0	1.0	<4.2
23	012S	09/05/89	1647	17.9C	<1.0	<1.0	<1.0	<1.0	<4.2
24	012B	09/05/89	1647	20.5C	<1.0	<1.0	<1.0	<1.0	<4.2
25	013S	09/12/89	1015	22.0C	18.0	18.0	2.0	9.0	<4.2
26	013B	09/12/89	1015	17.8C	<1.0	<1.0	<1.0	<1.0	<4.2
27	014S	09/19/89	1617	21.7C	39.0	39.0	3.0	17.0	<4.2
28	014B	09/19/89	1617	20.9C	<1.0	<1.0	<1.0	<1.0	<4.2
29	015S	09/26/89	1127	21.1C	14.0	14.0	4.0	8.0	<4.2
30	015B	09/26/89	1127	20.6C	<1.0	<1.0	<1.0	<1.0	<4.2
31	016S	10/03/89	1458	17.9C	153.0	150.0	8.0	5.0	<4.2
32	016B	10/03/89	1458	17.5C	92.0	90.0	3.0	<1.0	<4.2
33	017S	10/10/89	0845	14.1C	4.0	4.0	1.0	<1.0	<4.2
34	017B	10/10/89	0845	13.9C	2.0	2.0	1.0	<1.0	<4.2
35	018S	10/17/89	1508	12.1C	2.0	2.0	1.0	<1.0	<4.2
36	018B	10/17/89	1508	11.9C	<1.0	<1.0	1.0	1.0	<4.2
37	019S	10/24/89	1021	11.9C	7.0	7.0	7.0	1.0	<4.2
38	019B	10/24/89	1021	11.7C	7.0	7.0	9.0	<1.0	<4.2
39	020S	10/30/89	1345	14.4C	3.0	3.0	3.0	1.0	16.8
40	020B	10/30/89	1345	ND	ND	ND	ND	ND	ND
41	021S	11/07/89	0707	12.2C	<1.0	<1.0	1.0	1.0	<4.2
42	021B	11/07/89	0707	12.1C	1.0	1.0	2.0	3.0	<4.2
43	022S	11/14/89	1410	14.1C	1.0	1.0	1.0	1.0	<4.2
44	022B	11/14/89	1410	13.8C	1.0	1.0	1.0	<1.0	<4.2
45	023S	11/21/89	0837	7.90C	10.0	10.0	4.0	2.0	<4.2
46	023B	11/21/89	0837	7.50C	11.0	10.0	6.0	3.0	<4.2
47	024S	11/29/89	1346	6.90C	11.0	11.0	6.0	2.0	<4.2
48	024B	11/29/89	1346	6.90C	8.0	8.0	12.0	8.0	<4.2
49	025S	12/05/89	1811	6.90C	1.0	1.0	10.0	1.0	<4.2
50	025B	12/05/89	1811	7.20C	1.0	1.0	3.0	1.0	<4.2
51	026S	12/13/89	1356	6.00C	1.0	1.0	6.0	1.0	<4.2
52	026B	12/13/89	1356	6.10C	2.0	1.0	4.0	1.0	<4.2
53	027S	12/20/89	0711	6.00C	4.0	4.0	3.0	<1.0	<4.2
54	027B	12/20/89	0711	6.00C	1.0	1.0	2.0	<1.0	<4.2
55	028S	12/28/89	1331	6.00c	<1.0	<1.0	9.0	3.0	<4.2
56	028B	12/28/89	1331	5.70C	<1.0	<1.0	18.0	<1.0	<4.2
57	029S	01/03/90	1741	5.20C	2.0	2.0	15.0	1.0	<4.2
58	029B	01/03/90	1741	5.20C	4.0	4.0	6.0	1.0	<4.2
59	030S	01/09/90	1211	4.90C	30.0	30.0	6.0	1.0	<4.2
60	030B	01/09/90	1211	4.70C	1.0	1.0	3.0	<1.0	<4.2

61	031S	01/15/90	1600	3.00C	<1.0	<1.0	4.0	12.0	<4.2
62	031B	01/15/90	1600	3.80C	1.0	1.0	5.0	17.0	<4.2
63	032S	01/23/90	1111	4.50C	2.0	2.0	24.0	<1.0	<4.2
64	032B	01/23/90	1111	4.60C	3.0	3.0	26.0	<1.0	<4.2
65	033S	01/30/90	1542	3.40C	11.0	11.0	68.5	7.0	<4.2
66	033B	01/30/90	1542	2.90C	11.5	11.5	64.5	8.0	<4.2
67	034S	02/08/90	1811	4.20C	1.0	<1.0	26.0	<1.0	<4.2
68	034B	02/08/90	1811	4.50C	1.0	<1.0	26.0	<1.0	<4.2
69	035S	02/15/90	1518	2.80C	2.0	2.0	18.0	2.0	<4.2
70	035B	02/15/90	1518	2.90C	2.0	2.0	24.0	2.0	<4.2
71	036S	02/19/90	0758	3.10C	<1.0	<1.0	11.0	<1.0	<4.2
72	036B	02/19/90	0758	2.50C	<1.0	<1.0	12.0	<1.0	<4.2
73	037S	ʻ2/27/90	1437	2.90C	1.5	1.5	12.5	1.0	<4.2
74	037B	02/27/90	1437	2.50C	2.5	2.5	12.5	1.0	<4.2
75	038S	03/07/90	1100	9.50C	1.5	1.5	9.0	1.0	<4.2
76	038B	03/07/90	1100	9.60C	3.0	3.0	11.0	1.0	<4.2
77	039S	03/13/90	1418	12.2C	1.0	1.0	12.0	<1.0	<4.2
78	039B	03/13/90	1418	12.1C	<1.0	<1.0	11.5	1.0	<4.2
79	040S	03/22/90	0930	13.1C	2.0	2.0	12.0	2.0	<4.2
80	040B	03/22/90	0930	13.0C	1.0	1.0	4.0	2.0	<4.2
81	041S	03/27/90	1329	12.1C	2.0	2.0	6.0	1.0	<4.2
82	041B	03/27/90	1329	13.2C	1.5	1.5	8.5	<1.0	<4.2
83	042S	04/10/90	0739	ND	2.0	2.0	5.0	<1.0	2.8
84	024B	04/10/90	0739	ND	<1.0	<1.0	7.0	4.0	<2.8
85	043S	04/17/90	1630	ND	2.5	2.5	13.0	2.0	<3.3
86	043B	04/17/90	1630	ND	1.5	1.5	9.5	<1.0	<3.3
87	044S	04/24/90	1200	ND	<1.0	<1.0	7.0	<1.0	<3.3
88	044B	04/24/90	1200	ND	2.0	2.0	4.0	<1.0	<3.3
89	045S	05/01/90	1900	12.1C	2.5	2.5	9.5	2.0	<4.2
90	045B	05/01/90	1900	13.0C	6.0	6.0	10.0	1.0	<4.2
91	046S	05/09/90	1230	ND	1.0	1.0	11.0	<1.0	<4.2
92	046B	05/09/90	1230	ND	5.0	5.0	11.5	<1.0	<4.2
93	047S	05/17/90	1831	ND	51.5	51.5	4.0	<1.0	<4.2
94	047B	05/17/90	1831	ND	50.0	50.0	<1.0	<1.0	<4.2
95	048S	05/23/90	1151	13.7C	22.5	22.0	2.5	6.0	<4.2
96	048B	05/23/90	1151	13.6C	<1.0	<1.0	<1.0	8.0	<4.2
97	049S	05/30/90	0703	13.7C	35.5	17.5	1.0	12.0	<4.2
98	049B	05/30/90	0703	13.7C	8.5	8.5	<1.0	9.5	<4.2
99	050S	06/06/90	1207	15.7C	12.0	11.0	9.0	4.0	<4.2
100	050B	06/06/90	1207	15.5C	15.0	13.0	15.0	11.0	<4.2
101	051S	06/13/90	1617	19.9C	7.0	6.0	11.0	1.0	<4.2
102	051B	06/13/90	1617	20.1C	15.0	10.0	8.0	<1.0	<4.2
103	052S	06/20/90	1034	21.0C	20.0	18.0	16.0	2.0	<4.2
104	052B	06/20/90	1034	20.5C	19.0	18.0	12.0	4.0	<4.2
105	053S	06/28/90	1758	22.1C	15.5	15.5	1.5	1.5	<4.2
106	053B	06/28/90	1758	21.0	5.5	5.5	3.5	<1.0	<4.2
107	054S	07/02/90	0827	21.0C	6.5	6.0	5.0	<1.0	<4.2
108	054B	07/02/90	0830	22.0C	4.0	4.0	7.0	1.0	<4.2
109	055S	07/10/90	1429	23.0C	1.0	1.0	5.0	1.0	<4.2
110	055B	07/10/90	1429	23.1C	3.0	2.0	9.0	2.0	<4.2
111	056S	07/19/90	1030	23.0C	9.5	9.5	1.0	5.5	<4.2
112	056B	07/19/90	1030	24.0C	11.5	11.5	4.5	2.5	<4.2
113	057S	07/30/90	0630	24.0C	18.0	18.0	2.0	<1.0	<4.2
114	057B	07/30/90	0630	23.5C	16.0	16.0	1.0	<1.0	<4.2
115	058S	08/10/90	1545	24.0C	3.0	3.0	2.5	<1.0	<4.2
116	058B	08/10/90	1545	23.5C	1.0	1.0	1.0	<1.0	<4.2
117	059S	08/17/90	1026	24.0C	9.0	9.0	8.0	1.0	4.2
118	059B	08/17/90	1026	24.5C	6.0	5.0	6.0	<1.0	<4.2
119	060S	08/23/90	1510	22.0C	8.0	8.0	9.0	<1.0	4.2
120	060B	08/23/90	1510	21.0C	10.0	9.0	8.0	1.0	<4.2

121	061S		08/30/90	0800	21.5C	10.0	9.0	8.0	1.0	<3.3
122	016B		08/30/90	0800	21.0C	8.0	8.0	11.0	<1.0	<3.3
123	062S		09/05/90	1312	20.0C	5.5	5.0	5.0	<1.0	<3.3
124	062B		09/05/90	1312	20.0C	7.0	6.0	9.0	2.0	3.3
125	063S		09/12/90	0700	19.0C	10.0	9.0	6.0	4.0	7.2
126	063B		09/12/90	0700	18.9C	11.0	10.0	7.0	3.0	3.3
127	064S		09/19/90	1400	18.5C	16.0	16.0	17.0	5.0	10.0
128	064B		09/19/90	1400	18.5C	20.0	19.0	6.0	2.0	3.3
129	065S		09/26/90	1755	18.0C	10.0	7.0	9.0	1.0	<3.3
130	065B		09/26/90	1755	17.9C	12.0	10.0	13.0	<1.0	<3.3
131	066S		10/03/90	1200	18.0C	18.0	16.0	5.0	1.0	3.3
132	066B		10/03/90	1200	18.5C	12.0	12.0	9.0	2.0	7.2
133	067S	,	10/10/90	1800	16.9C	9.0	9.0	12.0	1.0	<3.3
134	067B		10/10/90	1800	17.5C	3.0	3.0	2.0	<1.0	<3.3
135	068S		10/16/90	1200	17.1C	13.0	12.0	12.0	3.0	<3.3
136	068B		10/16/90	1200	16.8C	15.0	13.0	11.0	1.0	3.3

APPENDIX D

PRELIMINARY HUMAN HEALTH ASSESSMENT

FOR SHELLFISH CONSUMPTION

Prepared by

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Dr. Wayne R. Munns, Jr.

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Dear Dr. Munns:

As we discussed today by telephone, enclosed are the spread-sheet calculations I have done on the data for Mercenaria mercenaria. I chose this species for the initial work because you identified it as the most important commercially and (likely) in terms of human consumption.

The first question I addressed was whether the data provided evidence that any of the pollutants of interest were present in higher concentrations in places that were relatively close to Alan harbor. For this purpose, I grouped the data into three categories:

o   Samples from Alan Harbor itself

o   Samples from stations in the channel of the bay containing Alan Harbor (GB, MV, NJ, and LAB)

o   Samples from the station not in the the channel of the bay containing Alan Harbor (PC).

Data for selected inorganic elements is presented on page 1; data for organic residues is summarized on page 2. It can be seen that the only residue that has a pattern that suggests the possibility that Alan Harbor may be making a measurable contribution is the sum of the measured PAH's.[1] I tested the statistical significance of the differences in the logarithms of the values shown,[2] and the differences between Alan Harbor and the other sites appear to be much larger than could be expected to result from random fluctuations:

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[1]Mean mercury concentrations are also larger in the Alan Harbor samples than in the mid-bay and PC samples, but in this case the findings are spotty because the levels are evidently very near the limit of detection; for purposes of this calculation I left the "0's" listed in the data you sent me as 0's, rather than making an assumption of some finite level below the limit of detection.

[2]Residue data of this type tend to be lognormally distributed, and because the t test presumes normal distributions in the sample data compared, it is generally more appropriate to compare the means of the logarithms of the sample data (and corresponding geometric means) rather than the untransformed numbers.

GROUP 1	Alan Harbor logΣPAH	Alan Harbor logΣPAH
Mean	2.9004	2.9004
Stdev	0.076141465	0.076141465
N	5	5

GROUP 2	Mid-Bay logΣPAH	PC logΣPAH
Mean	2.48914	2.42629
Stdev	0.30457251	0.08175087
N	15	5
pooled stdev	0.270995273	0.078995973
t	2.94	9.49
degrees freedom	18	8
p value (one-tailed)	<.005	<<.005

Because of the lack of differences between Alan Harbor levels and other Narragansett Bay sites for residues other than PAH's, and because I assume that it is rare for Rhode Islanders to confine their shellfish collection to Alan Harbor, I chose to base preliminary evaluations of the potential dosage of different toxicants to Rhode Island consumers on the arithmetic mean levels found in the samples from all sites (lines 48 and 108 on pages 1 and 2). Daily intakes (lines 53-54 and 119-120) for average Rhode Island clam consumers were based on

(A) the 18g/day shellfish consumption rate estimated from by Hoffman,[1] based on an apparently unpublished survey of Ward (1987),

(B) an assumption of a 12% ratio of dry weight to wet weight for shellfish samples,[2] and

(C) a conventional 70 kg human body weight.

For the metals, I compared these daily intakes with ADI's[3] and with average dietary intakes from other sources.[4] In using the ADI's I have assumed that the chromium is in the trivalent form.

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[1]Hoffman, E. J. (1988). "The first year of the Narragansett Bay project: Results and recommendations," A reporet submitted to the Narragansett Bay Project Management Committee, May.

[2]This is different than the 20% dry weight/wet weight ratio that is conventionally used for fish samples. I adopted the smaller figure on advice from Dr. Richard Wolke of the University of Rhode Island. A NOAA Technical Memorandum uses a value of 10% (NOS OMA 39--PCB and Chlorinated Pesticide Contamination in U.S. Fish and Shellfish: A Historical Assessment Report. p. 7), If you think it is potentially worthwhile, you might wish to revise the calculations using the actual dry weight/wet weight ratios from the individual samples as you actually measured them.

[3]U.S. Environmental Protection Agency (1986) Superfund Public Health Evaluation Manual, EPA/540/1-86/060.

[4]Gartrell, M. J., Craun, J. C., Pdrebarac, D. S., and Gunderson, E. L. (1985), "Pesticides, selected elements and other chemicals in adult total diet samples, Oct. 1978 - Sept. 1979," J. Assoc. Off. Anal. Chem. 68:862-875, as quoted by Hoffman, note 1 above.

and that the mercury is in the form of methyl mercury. (Please let me know if you have information that suggests otherwise). Overall, the expected doses of metals from Mercenaria mercenaria do not appear likely to make appreciable additions to overall dietary exposure, although in the light of the low-dose developmental effects that have recently been observed for lead, even the 4% addition to dietary lead dosage may be considered undesireable for women in their reproductive years. I have chosen to not use cancer potency factors for the inorganic elements that have carcinogenic forms (Ni, Cr, and As) because

o In the cases of Ni and Cr the EPA has only calculated potency factors for the inhalational route, and in the case of Cr, only for the hexavalent form.

o Arsenic is known to be present in fish predominantly in organic compounds thought to be much less active biologically than inorganic arsenic compounds. Additionally, it is my impression that the organic arsenic compounds are predominantly excreted by mammals unchanged, without being metabolized to the inorganics known to be carcinogenic. A serious uncertainty here, however, is that I do not specifically recall reading of a study of the forms of arsenic present in molluscan shellfish. If you have any indication what fraction of the measured arsenic might be present in inorganic forms or in relatively easily metabolizable organic forms, I will calculate presumptive cancer risks associated with that fraction.

For the carcinogenic organic residues, I have taken cancer potency factors from a recent EPA compilation,[1] with the exception of the PAH's. EPA evidently no longer publishes its benzo(a)pyrene cancer potency value--the one reproduced in the table is from the old Public Health Evaluation Manual (note 3 on the previous page). Conventionally, what I have seen people do to evaluate PAH risks is to assume that all PAH's have the same carcinogenic potency as benzo(a)pyrene. I don't think that is very satisfactory [in your data benzo(a)pyrene is only about 1% of total PAH's], but I have included a calculation on that basis just to see how it comes out. As can be seen in the table, if it were to be the case that the average PAH is as potent in causing cancer as benzo(a)pyrene, then the PAH cancer risk for average Narraganset Bay Quohogs would be the most significant potential risk of those evaluated--exceeding the PCB's by a few fold. Additionally, because the PAH's act by primary genetic mechanisms (reaction of electrophilic metabolites with DNA) we can be somewhat more confident that they will in fact pose finite cancer risks at low dosage than is the case at present for PCB's.

Because of the potential importance of PAH cancer risks to the overall evaluation, I did a literature search on Toxline to locate additional papers that might provide the basis for a more sophisticated analysis of PAH cancer potency. Two papers in particular stood out as potentially offering a useable set of potency numbers for different PAH congeners in relation to benzo(a)pyrene:

AU - Rugen PJ
AU - Stern CD
AU - Lamm SH
TI - Comparative carcinogenicity of the PAHs as a basis for acceptable exposure levels (AELs) in drinking water.
SI - TOXBIB/89/331973
SO - Regul Toxicol Pharmacol; VOL 9, ISS 3, 1989, P273-83
AB - The carcinogenicity of various polynuclear aromatic hydrocarbons (PAHs) has generally been demonstrated by their ability to act as complete carcinogens in the development of cancers in rodent skin tests. In order to develop proposed acceptable concentration levels for various PAHs in drinking water, we reviewed the studies that formed the basis for determining that these specific PAHs were carcinogenic in animals. We found that the relative potency of

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[1]U. S. Environmental Protection Agency, Health Effects Assessment Summary Tables--Third Quarter FY 1989

these PAHs varied over a range of many orders of magnitude. For example, the carcinogenic strength of benz[a]anthracene (BaA) is found to be about 1/2000th that of benzo[a]pyrene (BaP). We have used the calculated carcinogenic potency of the various PAHs relative to that of BaP as a means for proposing specific acceptable concentration levels in drinking water for each of the specific PAHs. BaP is the only carcinogenic PAH for which EPA has published an acceptable concentration level based on carcinogenicity. Based on the level EPA set for BaP (0.028 micrograms/liter), this methodology has provided for the specific PAHs a determination of proposed acceptable concentration levels quantitatively based on the same data that were used to qualitatively determine them to be animal carcinogens. We have proposed acceptable concentration levels for the carcinogenic PAHs in drinking water that range from 0.03 micrograms/liter for BaP to 6.5 micrograms/liter for BaA. We recommend that acceptable concentration levels for the various PAHs be based on their relative carcinogenic potencies rather than the EPA method of using the potency of only one specific PAH, BaP, to serve as the exposure level determinant for all PAHs. We further suggest that this methodology may be applicable to other classes of carcinogenic compounds. We have also found useful for the determination of acceptable concentration levels for the noncarcinogenic PAHs an analogous methodology based on the relative toxicities of the noncarcinogenic PAHs.

AU - Glass LR
AU - Easterly CE
TI - Ranking of PAH (Polynuclear Aromatic Hydrocarbons) Carcinogenic Potencies.
SI - NTIS/DE88004735
SA - Oak Ridge National Lab., TN
SA - Department of Energy, Washington, DC.
SO - Govt Reports Announcements & Index (GRA&I), Issue 14, 1988
AB - TD3: The proposed framework for the analysis of tumorigenicity data permits an independence from statistical models and simultaneously allows for a hierarchal approach to estimates of carcinogenic potency. The proposed framework makes no assumptions inferring that certain bioassays are more appropriate than others. It attempts to use all available data, and thereby provides a balance in the overall analysis by standardizing data for a test compound to the data for a reference compound and utilizing data of the central region of the resulting distribution as the summary statistic. This type of framework may be of value in guiding the development and interpretation of analytic measures. The results demonstrate a consistency in the ranking of the carcinogenic potencies of representative PAHs using information from the largest single source of toxicologic data in the public domain. Admittedly, these correlations will remain empirical relationships until the biological mechanisms are elucidated. 22 refs., 5 tabs. (ERA citation 13:019636) 11. international symposium on polynuclear aromatic hydrocarbons, Gaithersburg, MD, USA, 23 Sep 1987.

Unfortunately, the first paper is in a journal that we do not have at any of the universities in Boston. I have requested it on interlibrary loan, but that will take several weeks. I will also order the second report from NTIS. I will make a supplementary report when I have been able to review both of these documents. In passing, I should note that a congener-specific approach is also likely to be desirable for the PCB's, and is feasible based on the data that exist for binding to a key type of receptor that is also involved in some of the actions of dioxins. Are you in the process of evaluating the concentations of individual PCB congeners in your samples?

Sincerely,

Dale Hattis, Ph. D.
Principal Research Associate

cc: Russ Malcolm

D-6

D-7

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1							Preliminary Alan Harbor Data Analysis								
2	Dry Weight Data In PPM														
3	Mercenaria Mercenaria (=Quohogs=hard shell clams-relatively important commercially)								logs						
4		Cr	Pb	Ni	Cd	Hg	As		Cr	Pb	Ni	Cd	Hg	As	
5	Data For Alan Harbor Sites:														
6		0.66	1.3	11.55	1	0	6.03		-0.1804561	0.11394335	1.06258198	0	#NUM!	0.78031731	
7		0.1033	2.337	5.646	0.89	0.062	1.767		-0.9858997	0.36865871	0.75174087	-0.05061	-1.2076083	0.24723655	
8		0.1266	2.237	4.187	0.57	0.0573	1.94		-0.8975663	0.34966598	0.62190296	-0.2441251	-1.2418454	0.28780173	
9		0.29	0.87	11.03	0.87	0	5.64		-0.537602	-0.0604807	1.04257551	-0.0604807	#NUM!	0.7512791	
10		0.19	1.5	6.82	0.607	0	4.67		-0.7212464	0.17609126	0.83378437	-0.2168113	#NUM!	0.66931688	
11	Mean	0.274	1.649	7.847	0.787	0.024	4.009	Mean Log	-0.665	0.190	0.863	-0.114	#NUM!	0.547	
12	Gmean	0.216	1.547	7.286	0.768	#NUM!	3.525	Log Std Dev	0.32063976	0.17757388	0.18936677	0.10883531	#NUM!	0.25892568	
13	GSD	2.092	1.505	1.547	1.285	#NUM!	1.815								
14															
15	Data for Other Mid-Bay Sites That May Have Some Impact (GB, MV, NJ, and LAB)														
16		0.47	1.7	10.61	0.952	0	7.6		-0.3279021	0.23044892	1.02571538	-0.0213631	#NUM!	0.88081359	
17		1.37	0.48	11.98	0.705	0	14.36		0.13672057	-0.3187588	1.07845682	-0.1518109	#NUM!	1.15715444	
18		0.56	0.96	12.09	0.672	0	9.13		-0.251812	-0.0177288	1.0824263	-0.1726307	#NUM!	0.96047078	
19		2.13	1.48	22.21	0.878	0	14.47		0.3283796	0.17026172	1.34654856	-0.0565055	#NUM!	1.16046853	
20		0.65	0.9	11.42	0.625	0	9.68		-0.1870866	-0.0457575	1.0576661	-0.20412	#NUM!	0.98587536	
21		0.9	0.8	9.55	0.403	0	8.03		-0.0457575	-0.09691	0.98000337	-0.394695	#NUM!	0.90471555	
22		0.76	0.9967	14.3	0.637	0	6.16		-0.1191864	-0.0014355	1.15533604	-0.1958606	#NUM!	0.78958071	
23		0.73	0.69	18.77	0.69	0	8.91		-0.1366771	-0.1611509	1.22453306	-0.1611509	#NUM!	0.9498777	
24		0.51	1.1	11.47	0.711	0	8.5		-0.2924298	0.04139269	1.05956342	-0.1481304	#NUM!	0.92941893	
25		1.017	0.7033	10.46	0.4633	0	9.303		0.00732095	-0.1528594	1.01953168	-0.3341377	#NUM!	0.96862302	
26		0.5566	1.727	10.95	0.407	0.0357	2.28		-0.2544568	0.23729234	1.03941412	-0.3904056	-1.4473318	0.35793485	
27		0.69	2.49	7.013	0.337	0.0685	4.018		-0.1611509	0.39619935	0.84590384	-0.4723701	-1.1643094	0.60400993	
28		0.67	1.06	13.28	0.459	0	8.53		-0.1739252	0.02530587	1.12319808	-0.3381873	#NUM!	0.93094903	
29		0.76	1.19	15.14	0.526	0	10.2		-0.1191864	0.07554696	1.18012588	-0.2790143	#NUM!	1.00860017	
30		0.63	1.28	16.45	0.583	0	8.38		-0.2006595	0.10720997	1.2161659	-0.2343314	#NUM!	0.92324402	
31	Mean	0.827	1.170	12.913	0.603	0.007	8.637	Mean Log	-0.120	0.033	1.096	-0.237	#NUM!	0.901	
32	Gmean	0.759	1.078	12.463	0.579	#NUM!	7.958	Log Std Dev	0.17174892	0.18160627	0.11902959	0.12877155	#NUM!	0.2000672	
33	GSD	1.485	1.519	1.315	1.345	#NUM!	1.585								
34															
35									Cr	Pb	Ni	Cd	Hg	As	
36	Data for Site Across an Island Barrier and Less Likely to be Affected by Alan Harbor (PC)														
37		0.42	2.39	9.18	0.534	0	5.46		-0.3767507	0.3783979	0.96284268	-0.2724587	#NUM!	0.73719264	
38		0.5	2.36	9.18	0.642	0	6.15		-0.30103	0.372912	0.96284268	-0.192465	#NUM!	0.78887512	
39		0.51	2.62	11.68	0.762	0	5.49		-0.2924298	0.41830129	1.06744284	-0.118045	#NUM!	0.73957234	
40		0.54	2.78	10.59	0.896	0	5.08		-0.2676062	0.4440448	1.02489596	-0.1573908	#NUM!	0.70586371	
41		0.68	1.87	13.05	0.685	0	6.32		-0.1674911	0.27184161	1.11561051	-0.1643094	#NUM!	0.80071708	
42	Mean	0.530	2.404	10.736	0.664	0.000	5.700	Mean Log	-0.281	0.377	1.027	-0.181	#NUM!	0.754	
43	Gmean	0.524	2.383	10.635	0.659	#NUM!	5.681	Log Std Dev	0.0754382	0.06572234	0.06656543	0.05765289	#NUM!	0.03938756	
44	GSD	1.190	1.163	1.166	1.142	#NUM!	1.095								
45															
46	Data for All Sites Combined														
47															
48	Mean	0.657	1.513	11.464	0.652	0.009	7.124	Mean Log	-0.261	0.133	1.035	-0.201	#NUM!	0.801	
49	Gmean	0.548	1.358	10.845	0.629	#NUM!	6.321	Log Std Dev	0.28592654	0.21117301	0.15326513	0.12106293	#NUM!	0.23425707	
50	GSD	1.932	1.626	1.423	1.321	#NUM!	1.715								
51															
52	RI Clam Eater Daily Dose														
53	(µg/day)	1.4189904	3.2877344	24.7627584	1.40869152	0.0193104	15.3876672								
54	(mg/kg-day)	2.0271E-05	4.6682E-05	0.00035375	2.0124E-05	2.7586E-07	0.00021982								
55															
56	EPA ADI (mg/kg-day)	1	0.0014	0.02	0.00029	0.0003									
57	(chronic, non-cancer)	[Cr(III) only]				(alkyl Hg)									
58		Cr(VI) = 5e-3													
59															
60	Fraction of ADI	2E-05	0.03	0.02	0.07	9E-04									
61															
62	National Ave Diet (µg/day)		81.8		31.5	5.21									
63															
64	Fract RI Clam Eater		0.04		0.04	4E-03									
65	to National Ave Diet														
66															

D-8

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
67															
68	Dry Weight Data in PPB														
69	Mercenaria Mercenaria (=Quohogs=hard shell clams--relatively important commercially)														
70		alpha-BHC	gamma-BHC	alpha-chlorda	gamma-chlord	DDD	DDT	DDE	ΣDDT & Metab	HCB	ΣPCB's	ΣPAH's			
71	Data For Alan Harbor Sites														
72		0	0	0	1 77	0	0	0	0	0	249	968 75			
73		0	0	2 56	3 29	2 14	1 53	5 86	9 53	0 789	204	849 19			
74		0	0	1 75	2 85	3 79	0	5 03	8 82	0 667	149	702 17			
75		0	0	0	0	0	0	3 16	3 16	0 656	376	628 782			
76		0	0	0	1 49	0	0	0	0	0	235	874 636			
77	Mean	0.000	0.000	0.862	1 880	1.186	0.306	2 810	4 302	0 422	242 600	804 706			
78	Gmean	#NUM!	#NUM!	#NUM!	#NUM!	#NUM	#NUM!	#NUM!	#NUM!	#NUM!	231 768	795 055			
79	GSD	#NUM!	#NUM!	#NUM!	#NUM!	#NUM	#NUM!	#NUM!	#NUM!	#NUM!	1 399	1 192			
80															
81	Data for Other Mid-Bay Sites That May Have Some Impact (GB, MV, NJ, and LAB)														
82		0	0	0	0	0	0	0	0	0	125	171 637			
83		0	0	0	0	0	0	0	0	0	99 8	168 605			
84		0	0	0	0	0	0	0	0	0	54 8	2542 76			
85		0	0	0	0	0	0	0	0	0	61 3	188 226			
86		0	0	0	0	0	0	0	0	0	78 1	170 339			
87		0	0	1.79	2 81	0	0	0	0	0	149	275 478			
88		0	0	1.41	2 39	2.35	0	0	2 35	0	135	218 645			
89		0.52	0	1.95	2 15	1 28	0	4 2	5 48	0 61	71 4	209 584			
90		0.59	0	1.48	1 67	1.37	0	4 17	5 54	0 9	88 6	233 335			
91		0	0	1.74	2 32	0	0	5 29	5 29	0.65	315	222 267			
92												323 918			
93												401 95			
94												467 561			
95												429 33			
96												538 369			
97	Mean	0.111	0.000	0 837	1 134	0.500	0 000	1 366	1 866	0 216	117 800	437 467			
98	Gmean	#NUM!	#NUM!	#NUM!	#NUM!	#NUM	#NUM!	#NUM!	#NUM!	#NUM!	102 752	308 420			
99	GSD	#NUM!	#NUM!	#NUM!	#NUM!	#NUM	#NUM!	#NUM!	#NUM!	#NUM!	1 676	2 016			
100															
101															
102	Data for Site Across an Island Barrier and Less Likely to be Affected by Alan Harbor (PC)														
103		0	0	1 9	2 39	0	0	4 47	4 47	0 4	233	259 083			
104		0	0	0	2.12	0	0	0	1 0	0	141	251 93			
105		0	0	1 67	2.37	0	0	0	1 0	0	184	231 658			
106		0	0	1 79	2 3	0	0	4 1	4 1	0 53	227	242 034			
107		0	0	2.02	2.51	0	0	4 72	4 72	0 52	275	370 687			
108	Mean	0.000	0.000	1 476	2 338	0.000	0 000	2 658	2 658	0 290	212 000	271 078			
109	Gmean	#NUM!	#NUM!	#NUM!	2.334	#NUM	#NUM!	#NUM!	#NUM!	#NUM!	206 705	266 987			
110	GSD	#NUM!	#NUM!	#NUM!	1.064	#NUM	#NUM!	#NUM!	#NUM!	#NUM!	1 293	1 207			
111															
112	Data for All Sites Combined														
113															
114	Mean	0.056	0.000	1.003	1.622	0.547	0.077	2 050	2 673	0 286	172 550	488 990			
115	Gmean	#NUM!	#NUM!	#NUM!	#NUM!	#NUM	#NUM!	#NUM!	#NUM!	#NUM!	149 967	347 666			
116	GSD	#NUM!	#NUM!	#NUM!	#NUM!	#NUM	#NUM!	#NUM!	#NUM!	#NUM!	1 755	2 124			
117															
118	RI Clam Eater Daily Dose														
119	(µg/day)	0 00011988	0	0 00216648	0 00350244	0.00118044	0.00016524	0 004428	0 00577368	0 00061798	0 372708	1 05621797			
120	(mg/kg-day)	1 7126E-09	0	3 095E-08	5 0035E-08	1 6863E-08	2 3606E-09	6 3257E-08	8 2481E-08	8 8282E-09	5 3244E-06	1 5089E-05			
121	(based on 12% dry/wet														
122	and 18 g/day = 14 lbs/yr														
123	ave. clam consumption														
124	for RI clam eaters)														
125															
126	Cancer Potency Factor			1 3	1 3		0 34			1 7	7.7	11.5			
127	(mg/kg-day)^-1											[benzo(a)pyrene only]			
128												CAVEAT THIS VALUE NOT CURRENT			
129	RI Consumer Potential			4E-08	7E-08		8E-10			2E-08	4 1E-05	1 7E-04	[if ave PAH = benzo(a)pyrene]		
130	UCL Lifetime Risk											2 4E-06	[Based on benzo(a)pyrene only]		

Alan Harbor Data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
131	PAH Summation		(AH	AH	AH	(AH	AH	NJ	NJ	NJ	NJ	NJ	(B	(B	(B
132	Fluorene		4.61	5.17	4.74	3.75	3.08	1.05	1.05	.22	1.25	1.21	1.46	2.21	1.63
133	Phenanthrene		27.2	13.2	15.6	1.04	17.9	4.13	3.69	223	5.51	4.98	3.64	4.54	4.41
134	Anthracene		5.13	8.17	5.85	3.39	4.68	0.811	0.707	52.4	0.706	0.826	1.12	1.28	1.27
135	C1 Phen + Anth		27.9	33.4	31.3	24.6	37.7	7.91	8.13	103	8.06	8.1	12.2	10.4	9.49
136	C2		53.4	84.8	64	61.5	91.5	18	17.2	67	17.8	18.3	35.9	26.3	25.4
137	C3		38.2	80.2	36.2	37.3	62.5	12	11.7	297	13.2	11.7	26.5	17.3	18.3
138	C4		11.1	25.3	13.8	11	21	5.33	5.74	7.56	6.07	3.94	5.89	4.08	5.12
139	Fluoranthene		307	250	214	226	276	45.3	46.5	440	35.2	44	77.9	66	57.7
140	Pyrene		264	174	153	162	207	32.7	31.8	306	24.7	29.8	56	45.9	44
141	Benz(a)anthracene		40	35	27.6	15.1	25.1	3.8	4.73	169	4.42	5.77	4.28	7.49	2.92
142	Chrysene		48.5	39.7	31.9	29	40.3	8.12	8.47	105	8.45	8.36	11.2	7.53	9.59
143	Σ Benzofluoranthenes		48.4	37.7	37.1	16.7	28.3	7.95	7.51	234	11.7	8.9	8.11	6.3	6.51
144	Benzo(e)pyrene		24	8.49	10	11.7	19	5.99	6.01	82.8	8.53	6.68	7.69	6.32	6.46
145	Benzo(a)pyrene		8.43	1.81	3.54	3.14	4.72	1.66	1.17	98.2	3.46	1.62	1.38	0.931	1.48
146	Perylene		3.14	4.02	2.39	2.73	4.21	1.35	0.927	26.7	2.81	1.14	1.07	0.509	0.913
147	Benzo(ghi)perylene		9.15	4.81	5.92	3.75	5.98	2.96	2.61	57.5	6.16	2.73	3.23	2.31	2.68
148	Σ MW 276		24.5	16.2	21.8	7.3	13.2	6.59	5.1	229	13.9	5.26	6.54	4.63	5.67
149	Dibenz(a,h)anthracene		2.05	1.82	1.79	0.582	0.956	0.486	0.294	22.1	0.8	0.571	0.348	0.315	0.278
150	Σ MW 278 PAH		10.4	13.6	7.39	3.88	4.68	2.79	2.18	94.4	6.05	2.5	2.01	1.59	2.18
151	Coronene		2.06	3.2	1.85	1.04	1.55	0.48	0.387	17.4	.1	0.542	5.89	0.39	0.643
152	Σ MW 302 PAH		9.58	8.6	12.4	3.28	5.28	2.23	2.7	154	8.45	3.41	3.12	2.32	2.94
153	Total Measured PAH's		968.75	849.19	702.17	628.782	874.636	171.637	168.605	2542.76	188.226	170.339	275.478	218.645	209.584

D-9

D-10

	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD
67															
68															
69															
70		alpha-BHC	gamma-BHC	alpha-chlorda	gamma-chlord	DDD	DDT	DDE	ΣDDT & Metab	HCB	ΣPCBs	ΣPAHs			
71															
72		#NUM!	#NUM!	#NUM!	0.24797327	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	2.39619935	2.98621172			
73		#NUM!	#NUM!	0.40823997	0.5171959	0.33041377	0.18469143	0.76789762	0.9790929	-0.102923	2.30963017	2.92900487			
74		#NUM!	#NUM!	0.24303805	0.45484486	0.57863921	#NUM!	0.70156799	0.94546859	-0.1758742	2.17318627	2.84644227			
75		#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	0.49968708	0.49968708	-0.1830962	2.57518784	2.7985001			
76		#NUM!	#NUM!	#NUM!	0.17318627	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	2.37106786	2.94182735			
77	Mean Log	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	2.365	2.900			
78	Log Std Dev.	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	0.14581449	0.07614647			
79															
80															
81															
82		#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	2.09691001	2.23461092			
83		#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	1.99913054	2.22687045			
84		#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	1.73878056	3.40530537			
85		#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	1.78746047	2.27467961			
86		#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	1.89265103	2.23131409			
87		#NUM!	#NUM!	0.25285303	0.44870632	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	2.17318627	2.44008692			
88		#NUM!	#NUM!	0.14921911	0.3783979	0.37106786	#NUM!	#NUM!	0.37106786	#NUM!	2.13033377	2.33973955			
89		-0.2839967	#NUM!	0.29003461	0.33243846	0.10720997	#NUM!	0.62324929	0.73878056	-0.2146702	1.85369821	2.32135812			
90		-0.229148	#NUM!	0.17026172	0.22271647	0.13672057	#NUM!	0.62013605	0.74350976	-0.0457575	1.94743372	2.36797989			
91		#NUM!	#NUM!	0.24054925	0.36548798	#NUM!	#NUM!	0.72345567	0.72345567	-0.1870866	2.49831055	2.34687499			
92												2.51043508			
93												2.60417203			
94												2.66983828			
95												2.63279124			
96												2.73108004			
97	Mean Log	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	2.012	2.489			
98	Log Std Dev	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	0.22420131	0.30457251			
99															
100															
101		alpha-BHC	gamma-BHC	alpha-chlorda	gamma-chlord	DDD	DDT	DDE	ΣDDT & Metab	HCB	ΣPCBs	ΣPAHs			
102															
103		#NUM!	#NUM!	0.2787536	0.3783979	#NUM!	#NUM!	0.65030752	0.65030752	-0.39794	2.36735592	2.41343892			
104		#NUM!	#NUM!	#NUM!	0.32633586	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	2.14921911	2.40127989			
105		#NUM!	#NUM!	0.22271647	0.37474835	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	2.26481782	2.3648473			
106		#NUM!	#NUM!	0.25285303	0.36172784	#NUM!	#NUM!	0.61278386	0.61278386	-0.2757241	2.35602586	2.38387638			
107		#NUM!	#NUM!	0.30535137	0.39967372	#NUM!	#NUM!	0.673942	0.673942	-0.2839967	2.43933269	2.56900736			
108	Mean Log	#NUM!	#NUM!	#NUM!	0.368	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	2.315	2.426			
109	Log Std Dev.	#NUM!	#NUM!	#NUM!	0.02707381	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	0.11167343	0.08175087			
110															
111															
112															
113															
114	Mean Log	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	2.176	2.541			
115	Log Std Dev.	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	0.24417189	0.32721148			
116															
117															
118															
119															
120															
121															
122															
123															
124															
125															
126															
127															
128															
129															
130															

Alan Harbor Data

	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD
131	GB	CB	MV	MV	MV	MV	MV	PC	PC	PC	PC	IPC	Averages, All Samples		
132	1 91	1.65	1 15	1 44	2.82	3 35	2 53	1 61	1 9	1 83	0 922	0 787	3 00	Fluorene	
133	3 92	4.63	4 55	5 85	7 35	7 94	7 03	4 05	5 28	6 22	4 46	5 66	15 83	Phenanthrene	
134	1 15	1 02	2 23	2 46	2 34	2 71	2 53	0 952	1 38	1 57	1 17	1 51	4 29	Anthracene	
135	10 7	9.69	15	21	18	17 5	22 3	115	12 3	11 8	12 1	15 6	19 99	C1 Phen + Anth	
136	28 1	25 1	42 4	57 2	53 8	46 5	60 7	212	23 6	20 9	23 3	35 6	40 78	C2	
137	19 2	16 7	29 9	36 6	34 2	30	41 5	16 5	16 2	15	16 9	31 7	27 97	C3	
138	5 78	4 65	11 6	16 4	10 8	10 7	15 8	8 81	8 5	6 71	6 67	15 9	9 93	C4	
139	66 2	66 8	79 9	94 3	137	117	158	55 7	62 7	51 9	57 2	77	124 37	Fluoranthene	
140	48 3	4 6	62 6	72 4	99 8	92 6	115	56 7	55 9	50 9	52 7	82 1	94 64	Pyrene	
141	7 1	6 4	9 65	8 64	12 8	12 4	16 4	7 55	5 15	7 13	6 67	10 8	18 24	Benz(a)anthracene	
142	9 82	9 38	13 2	18 2	21.5	21	24 4	15 5	15	12 5	12	15 6	21 77	Chrysene	
143	8 46	8 11	23 3	24 8	16 4	19 2	18 2	15	10 8	11 6	10 7	19 4	25 81	Σ Benzofluoranthenes	
144	7 16	6 61	8 44	7 81	10 7	11 5	15 5	13 7	7 96	11 6	10 7	16 7	13 20	Benzo(e)pyrene	
145	1 06	0 88	1 94	3 19	3 05	5.19	3 62	2 27	2 76	2 21	2 15	4 05	6 56	Benzo(a)pyrene	
146	1 17	0 82	1 08	1 83	2 11	2 18	1 59	1 85	1 35	1 97	2 24	3 54	3 03	Perylene	
147	3	2 64	3 63	5 47	4 61	5 35	5 96	5 45	3 45	4 01	4 4	6 61	6 57	Benzo(ghi)perylene	
148	5 73	5.96	8 82	13 4	17 6	12.1	14 5	10 7	8 91	7 67	9 24	14 6	19 56	Σ MW 276	
149	0 246	0.23	0 451	0 84	0 841	1 42	0 809	0 511	3 77	0 644	0 465	0 8	1 74	Dibenz(a,h)anthracene	
150	1.99	2.05	1.93	3.32	6.05	5 84	5 74	4 51	0 554	2 77	3 22	6 52	7 93	Σ MW 278 PAH	
151	0.519	0.507	0.627	1.86	1.01	1.88	1 62	1 09	0 886	0 624	0 867	1	1 96	Coronene	
152	1.82	2.44	3 52	4.94	4.78	2.97	4.64	3 93	3 58	2 1	3 96	5 21	10 49	Σ MW 302 PAH	
153	233.335	222.267	323.918	401.95	467.561	429 33	538 369	259 083	251.93	231 658	242 034	370 687	477 64	Total Measured PAH's	

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APPENDIX E

ANALYTICAL CHEMISTRY INTERCALIBRATION

INTRODUCTION

An intercalibration exercise involving TRC-ECI, URI-GSO, and ERLN was conducted to establish the comparability of analytical chemistry data obtained by each group involved in investigations at NCBC Davisville. This exercise involved independent analyses of three certified marine sediments, as well as splits of samples obtained at NCBC Davisville. Samples (ground and seep water) collected simultaneously from field sites were analyzed to provide additional points of comparison.

RESULTS

The results of TRC-ECI's analyses of the certified marine sediments and of soil samples follow. ERLN's certified marine sediment results are given in Table E-1. Since ERLN is a marine laboratory, analyses of soil splits were not conducted by this facility.

To date, ERLN's analyses have been limited to PCBs and pesticides. These contaminants were not included in TRC-ECI's measurements. Since TRC-ECI's results associated with ground and seep water have yet to be released, comparisons of these data with results obtained by URI-GSO and ERLN are not possible at this time. A separate comparison will be made when all data become available.

Table E.1. Results of ERLN analyses of certified marine sediments.

| Contaminant | Sediment | | | | | |
| | LCS-01-MET | | LCS-02-MET | | LCS-03-MET | |
	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2
A1242	8.38	8.33				
A1254	75.6	81.6	10.35	4.46	7.28	8.11
Total PCB	83.9	89.9	10.35	4.46	7.28	8.11
CB052	1.81	1.82	0.35	0.24	0.16	0.17
CB153	3.03	3.30	0.48	0.22	0.35	0.35
CB180	1.39	1.51	0.17	0.06	0.15	0.17
a-CHLOR	0.25	0.27	0.08	0.07		
o,p'-DDD	3.01	3.56	0.60	0.52	0.33	0.36
p,p'-DDD	14.9	16.6	3.07	2.52	2.03	1.89
o,p'-DDT			0.24	0.23		
p,p'-DDT	0.69	0.52	0.57	0.65		

ALLIANCE Technologies Corporation

22 August 1990

Donald Cobb
Environmental Protection Agency
27 Tarzwell Drive
Narragansett, RI   02882
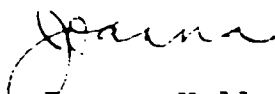
Subject: Results of Split Sample Analysis at NCBC Davisville
(8-400-063-0-R401-0)

Dear Don,

Enclosed please find results of laboratory analysis of four split
samples: S-09-01-00-S, S-09-01-00-S, S-09-02-00-S, S-09-03-00-S,
S-09-04-00-S, and three certified marine sediments: LCS-01-MET,
LCS-02-MET, LCS-03-ORG. Reported results have been validated and
the appropriate qualifiers applied to the data.

I look forward to receiving EPA's data for comparison.

Sincerely,

Joanna Hall

cc: File

kas0022jh

E-4

RESULTS OF TRC ANALYSIS OF CERTIFIED MARINE SEDIMENTS

NRCC ID: MESS-1;   TRC ID: LCS-01-MET;   COMPUCHEM ID: 332718, 332722

ELEMENT	TRUE VALUE (mg/Kg)	SAMPLE 332718 (mg/Kg)	% Rec.	SAMPLE 332722 (mg/Kg)	% Rec.	RPD
Antimony (Sb)	0.73 ± 0.08	6.6U	a	6	a	--
Arsenic (As)	10.6 ± 1.2	12.1	114	7.2	67.9	51
Beryllium (Be)	1.9 ± 0.2	0.58	30.5	0.38	20	42
Cadmium (Cd)	0.59 ± 0.10	1.6U	a	1.0U	a	--
Chromium (Cr)	71 ± 11	64.8	91.2	38.3	53.9	51
Cobalt (Co)	10.8 ± 1.9	15.7	145	9.6	88.9	48
Copper (Cu)	25.1 ± 3.8	29.3	117	16.1	64.1	58
Lead (Pb)	34.0 ± 6.1	33.4	98.2	21	61.8	46
Manganese (Mn)	513 ± 25	279	54.4	165	32.2	51
Mercury (Hg)	b	0.38	b	0.22	b	53
Nickel (Ni)	29.5 ± 2.7	67.6	229	40.6	138	50
Selenium (Se)	0.34 ± 0.06	3.2U	a	2.0U	a	--
Vanadium (V)	72.4 ± 5.3	81.3	112	49.4	68.2	49
Zinc (Zn)	191 ± 17	160	83.8	99.6	52.2	47

NRCC ID: BCSS-1;   TRC ID: LCS-02-MET;   COMPUCHEM ID: 332724, 332725

ELEMENT	TRUE VALUE (mg/Kg)	SAMPLE 332724 (mg/Kg)	% Rec.	SAMPLE 332725 (mg/Kg)	% Rec.	RPD
Antimony (Sb)	0.59 ± 0.06	4.2U	a	4.5	a	--
Arsenic (As)	11.1 ± 1.4	5.5	50	7	63.1	24
Beryllium (Be)	1.3 ± 0.3	0.62	47.7	0.48	36.9	25
Cadmium (Cd)	0.25 ± 0.4	1.0U	a	1.0U	a	--
Chromium (Cr)	123 ± 14	22.7	18.5	23.2	18.9	2
Cobalt (Co)	11.4 ± 2.1	9.7	85.1	10	87.7	3
Copper (Cu)	18.5 ± 2.7	23.6	128	23.7	128	0
Lead (Pb)	22.7 ± 3.4	26.4	116	26.8	118	2
Manganese (Mn)	229 ± 15	291	127	295	129	1
Mercury (Hg)	b	0.28	b	0.23	b	20
Nickel (Ni)	55.3 ± 3.6	17.4	31.5	23.6	42.7	30
Selenium (Se)	0.43 ± 0.06	2.0U	a	2.0U	a	--
Vanadium (V)	93.4 ± 4.9	41.3	44.2	42.8	45.8	4
Zinc (Zn)	119 ± 12	171	144	171	144	0

NRCC ID: SES-1;   TRC ID: LCS-03-ORG;   COMPUCHEM ID: 332713, 332714

COMPOUND	TRUE VALUE (mg/Kg)	SAMPLE 332713 (mg/Kg)	% Rec.	SAMPLE 332714 (mg/Kg)	% Rec.	RPD
Naphthalene	1.7	0.56	32.9	0.74	43.5	28
Acenaphthene	0.59	0.08	13.6	0.084	14.2	5
Fluorene	0.55	0.13	23.6	0.15	27.3	14
Phenanthrene	1.05	0.47	44.8	0.55	52.4	16
Anthracene	0.02	0.34U	a	0.34U	a	--
Fluoranthene	1.35	0.67	49.6	0.68	50.4	1
Pyrene	2.4	1	41.7	1.3	54.2	26
Benz[a]anthracene	0.5	0.15	30	0.19	38	24
Chrysene	1.1	0.48	43.6	0.61	55.2	24
Benzo[a]pyrene	0.15	0.035	23.3	0.045	30	25
Benzo[b]fluoranthene	b	0.53	--	0.62	--	16
Benzo[k]fluoranthene	b	0.97	--	1.3	--	29
Benzo[ghi]perylene	0.69	0.47	68.1	0.49	71	4
Dibenz[a,h]anthracene	0.6	0.43	71.7	0.47	78.3	9
Indeno[1,2,3-cd]pyrene	0.8	0.47	58.8	0.51	63.8	8

NRCC = National Research Council Canada
RPD = Relative Percent Difference
U = Analyte not detected at concentration provided.
(a) True value is less than reported detection limit.
(b) True value not determined.

RESULTS OF THC ANALYSIS OF SOIL SAMPLES SPLIT WITH EPA NARRAGANSETT

	S-09-01-00-S		S-09-02-00-S		S-09-03-00-S		S-09-04-00-S	
METALS (mg/kg)								
Antimony	25		65.3		23.8	U	21	U
Arsenic	11.3		32.5		10.7		16.5	
Beryllium	0.83		1.3		1.2		1	
Cadmium	5.8		4.1		5		11.2	
Chromium	176		560		67.5		65.7	
Copper	1210		1730		315		444	
Lead	1140		4070		370		656	
Mercury	1.4		0.23	U	0.33	U	0.46	
Nickel	148		92.5		34.3		56.8	
Selenium	0.42	U	0.44	U	0.73	U	3.4	U
Silver	6.5		3.1		4.3		3.7	
Thallium	1.7	U	1.8	U	3	U	2.8	U
Zinc	1890		2470		757		1150	
Barium	97.4		74		59.8		221	
Iron	144000		369000		58000		143000	
Manganese	901		1160		212		509	
Vanadium	134		77.9		69.3		61.5	
Aluminum	4710		3260		9930		8850	
Cobalt	32.9		59.8		14.8		33.1	
Magnesium	2700		3380		5420		7650	
Calcium	2650		4000		5360		3600	
Sodium	5060		4120		10700		4120	
Potassium	1570		721	U	1430		846	U
VOLATILES (ug/kg)								
Benzene	7	U	7	U	12	U	11	U
Bromoform	7	U	7	U	12	U	11	U
Carbon tetrachloride	7	U	7	U	12	U	11	U
Chlorobenzene	7	U	7	U	12	U	11	U
Dibromochloromethane	7	U	7	U	12	U	11	U
Chloroethane	14	U	14	U	24	U	22	U
Chloroform	7	U	7	U	16		11	U
Bromodichloromethane	7	U	7	U	12	U	11	U
1,1-Dichloroethane	7	U	7	U	12	U	11	U
1,2-Dichloroethane	7	U	7	U	12	U	11	U
1,1-Dichloroethene	7	U	7	U	12	U	11	U
1,2-Dichloropropane	7	U	7	U	12	U	11	U
Cis-1,3-Dichloropropene	7	U	7	U	12	U	11	U
Ethylbenzene	7	U	7	U	12	U	11	U
Bromomethane	14	U	14	U	24	U	22	U
Chloromethane	14	U	14	U	24	U	22	U
Methylene chloride	30	UJ	27	UJ	60	UJ	77	UJ
1,1,2,2-Tetrachloroethane	7	U	7	U	12	U	11	U
Tetrachloroethene	7	U	7	U	12	U	11	U
Toluene	7	U	7	U	12	U	11	U
1,1,1-Trichloroethane	7	U	7	U	12	U	11	U
1,1,2-Trichloroethane	7	U	7	U	12	U	11	U
Trichloroethene	7	U	7	U	12	U	11	U
Vinyl chloride	14	U	14	U	24	U	22	U
Trans-1,3-Dichloropropene	7	U	7	U	12	U	11	U
Styrene	7	U	7	U	12	U	11	U
Acetone	110		14	U	55	UJ	60	
2-Butanone	14	U	14	U	24	U	22	U
Carbon disulfide	7	U	7	U	12	U	11	U
2-Hexanone	14	U	14	U	24	U	22	U
4-Methyl-2-pentanone	14	U	14	U	24	U	22	U
Vinyl acetate	14	U	14	U	24	U	22	U
Xylenes (Total)	7	U	7	U	12	U	11	U
1,2-Dichloroethene(Total)	7	U	7	U	12	U	11	U

RESULTS OF TRC ANALYSIS OF SOIL SAMPLES SPLIT WITH EPA NARRAGANSETT

SEMIVOLATILES (ug/kg)	S-09-01-00-S		S-09-02-00-S		S-09-03-00-S		S-09-04-00-S	
Acenaphthene	120	J	160	J	150	J	86	J
Acenaphthylene	450	U	460	U	790	U	720	U
Anthracene	270	J	360	J	190	J	79	J
Benzo(a)anthracene	980		810		610	J	350	J
Benzo(a)pyrene	780		600		540	J	440	J
Benzo(b)/Benzo(k)fluoranthene	1500		1200		970		770	
Benzo(g,h,i)perylene	260	J	210	J	240	J	240	J
bis(2-Chloroethoxy)methane	450	U	460	U	790	U	720	U
bis(2-Chloroethyl)ether	450	U	460	U	790	U	720	U
bis(2-Chloroisopropyl)ether	450	U	460	U	790	U	720	U
bis(2-Ethylhexyl)phthalate	400	J	620		1000		530	J
4-Bromophenyl phenyl ether	450	U	460	U	790	U	720	U
Butyl benzyl phthalate	450	U	460	U	790	U	720	U
2-Chloronaphthalene	450	U	460	U	790	U	720	U
4-Chlorophenyl phenyl ether	450	U	460	U	790	U	720	U
Chrysene	1000		890		690	J	420	J
Dibenzo(a,h)anthracene	170	J	120	J	170	J	120	J
1,2-Dichlorobenzene	450	U	460	U	790	U	720	U
1,3-Dichlorobenzene	450	U	460	U	790	U	720	U
1,4-Dichlorobenzene	450	U	460	U	790	U	720	U
3,3'-Dichlorobenzidine	900	U	920	U	1600	U	1400	U
Diethyl phthalate	450	U	460	U	790	U	720	U
Dimethyl phthalate	450	U	460	U	790	U	720	U
Di-n-butyl phthalate	190	J	460	U	190	J	720	U
2,4-Dinitrotoluene	450	U	460	U	790	U	720	U
2,6-Dinitrotoluene	450	U	460	U	790	U	720	U
Di-n-octyl phthalate	450	U	460	U	790	U	720	U
Fluoranthene	1700		1700		1300		620	J
Fluorene	150	J	160	J	160	J	84	J
Hexachlorobenzene	450	U	460	U	790	U	720	U
Hexachlorobutadiene	450	U	460	U	790	U	720	U
Hexachlorocyclopentadiene	450	U	460	U	790	U	720	U
Hexachloroethane	450	U	460	U	790	U	720	U
Indeno(1,2,3-cd)pyrene	280	J	210	J	240	J	210	J
Isophorone	450	U	460	U	790	U	720	U
Naphthalene	450	U	460	U	790	U	120	J
Nitrobenzene	450	U	460	U	790	U	720	U
N-Nitroso-di-n-propylamine	450	U	460	U	790	U	720	U
N-Nitrosodiphenylamine(1)	450	U	460	U	790	U	720	U
Phenanthrene	1300		1400		1200		460	J
Pyrene	1300		1300		1100		530	J
1,2,4-Trichlorobenzene	450	U	460	U	790	U	720	U
Benzyl alcohol	450	U	460	U	790	U	720	U
4-Chloroaniline	450	U	460	U	790	U	720	U
Dibenzofuran	71	J	87	J	86	J	720	U
2-Methylnaphthalene	450	U	460	U	790	U	720	U
2-Nitroaniline	2200	U	2200	U	3800	U	3500	U
3-Nitroaniline	2200	U	2200	U	3800	U	3500	U
4-Nitroaniline	2200	U	2200	U	3800	U	3500	U
2-Chlorophenol	450	U	460	U	790	U	720	U
2,4-Dichlorophenol	450	U	460	U	790	U	720	U
2,4-Dimethylphenol	450	U	460	U	790	U	720	U
4,6-Dinitro-2-methylphenol	2200	U	2200	U	3800	U	3500	U
2,4-Dinitrophenol	2200	U	2200	U	3800	U	3500	U
2-Nitrophenol	450	U	460	U	790	U	720	U
4-Nitrophenol	2200	U	2200	U	3800	U	3500	U
4-Chloro-3-methylphenol	450	U	460	U	790	U	720	U
Pentachlorophenol	2200	U	2200	U	3800	U	3500	U

RESULTS OF TRC ANALYSIS OF SOIL SAMPLES SPLIT WITH EPA NARRAGANSETT

	S-09-01-00-S		S-09-02-00-S		S-09-03-00-S		S-09-04-00-S	
Phenol	450	U	460	U	790	U	720	U
2,4,6-Trichlorophenol	450	U	460	U	790	U	720	U
2-Methylphenol	450	U	460	U	790	U	720	U
4-Methylphenol	450	U	460	U	790	U	720	U
Benzoic acid	63	J	2200	U	210	J	3500	U
2,4,5-Trichlorophenol	2200	U	2200	U	3800	U	3500	U
PESTICIDES/PCBs (ug/kg)								
Aldrin	11	U	110	U	190	U	170	U
Alpha-BHC	11	U	110	U	190	U	170	U
Beta-BHC	11	U	110	U	190	U	170	U
Gamma-BHC (Lindane)	11	U	110	U	190	U	170	U
Delta-BHC	11	U	110	U	190	U	170	U
4,4'-DDT	22	U	220	U	380	U	350	U
4,4'-DDE	22	U	220	U	380	U	350	U
4,4'-DDD	22	U	220	U	380	U	350	U
Dieldrin	22	U	220	U	380	U	350	U
Endosulfan I	11	U	110	U	190	U	170	U
Endosulfan II	22	U	220	U	380	U	350	U
Endosulfan sulfate	22	U	220	U	380	U	350	U
Endrin	22	U	220	U	380	U	350	U
Heptachlor	11	U	110	U	190	U	170	U
Heptachlor epoxide	11	U	110	U	190	U	170	U
PCB-1242	110	U	1100	U	1900	U	1700	U
PCB-1254	220	U	2200	U	3800	U	3500	U
PCB-1221	110	U	1100	U	1900	U	1700	U
PCB-1232	110	U	1100	U	1900	U	1700	U
PCB-1248	110	U	1100	U	1900	U	1700	U
PCB-1260	220	U	2200	U	3800	U	3500	U
PCB-1016	110	U	1100	U	1900	U	1700	U
Toxaphene	220	U	2200	U	3800	U	3500	U
p,p'-Methoxychlor	110	U	1100	U	1900	U	1700	U
Endrin ketone	22	U	220	U	380	U	350	U
Alpha chlordane	110	U	1100	U	1900	U	1700	U
Gamma chlordane	110	U	1100	U	1900	U	1700	U
CYANIDE (mg/kg)	0.67	U	0.69	U	1.2	U	1.1	U
pH	7.4		6.9		7.1		7.7	
PERCENT SOLIDS	73.4		72.3		42.2		45.5	
PERCENT MOISTURE, UNDECANTED	27		28		58		54	

U = Analyte not found.

J = Analyte concentration is an estimate.

UJ = Analyte detection limit is an estimate.

APPENDIX F

TRACE METAL CONCENTRATIONS*

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* The following chemical concentration data are organized by sample matrix. Individual field replicates are identified by unique sample numbers (SAMPNUM). Instrumental replicates are identified by REP. Station designations follow the terminology described in the main body of this report. Sample collection dates follow the format YYMMDD. All contaminant abbreviations and acronyms are described in the text.

Entries of "0.0" or "nd" indicate contaminant levels below analytical detection limits, rather than actual zero concentrations. Entries of "nm" indicate the contaminant not to have been measured in that sample.

TABLE F-1. TRACE METAL CONCENTRATIONS (PPM DRY WT) IN SUBTIDAL SEDIMENTS

Sampnum	Stat	Date	Cu	Zn	Cr	Pb	Ni	Cd	Mn	Fe	Ag	Hg	As
798000	AH8	881031	127.3	193.6	52.59	68.42	24.44	1.019	201.2	26015	1.030	0.0000	9.980
798001	AH3	881031	96.55	176.9	60.06	64.90	20.45	1.258	229.2	28593	1.430	0.4850	3.970
798002	AH2	881103	82.89	142.9	58.05	54.16	15.73	0.7870	231.3	27015	1.160	0.2740	4.110
798006	AH5	881103	76.52	133.5	41.04	41.71	19.12	0.6710	179.5	22058	0.7400	0.0000	7.220
798007	AH10	890209	80.48	127.7	41.37	42.71	18.28	0.5650	182.2	21480	0.8900	0.0000	6.870
798018	NJ1	881031	36.49	85.44	37.48	29.07	14.49	0.0780	167.4	17198	0.5000	0.0000	5.230
798019	NJ2	881031	30.07	74.29	31.50	24.90	12.59	0.0740	157.0	15091	0.4600	0.0000	4.340
798020	NJ3	881101	21.65	57.26	22.76	18.70	9.510	0.0630	116.9	11321	0.3300	0.0000	2.780
798021	NJ4	881101	13.18	42.18	16.14	12.37	7.450	0.0140	102.3	9446	0.2100	0.0000	2.100
798022	NJ5	881101	12.25	44.58	15.50	13.30	6.950	0.0290	104.7	9333	0.2000	0.0000	2.150
798023	GB1	881031	11.59	26.30	9.940	9.810	2.890	0.0260	64.77	3390	0.2200	0.0000	1.650
798024	GB2	881031	9.220	20.79	7.700	8.240	2.000	0.0480	43.63	2542	0.1900	0.0000	0.9100
798025	GB3	881031	6.390	16.06	5.900	6.560	1.440	0.0000	39.92	1860	0.1400	0.0000	1.000
798026	GB4	881031	25.59	46.96	19.20	19.60	5.180	0.1070	82.62	5918	0.3600	0.0000	1.800
798027	GB5	881031	7.390	20.99	7.230	43.75	1.830	0.0130	46.35	2449	0.1600	0.0000	0.9500
798028	MV1	881031	70.90	109.5	61.94	46.80	12.19	0.4290	203.6	18897	1.290	0.3350	3.460
798029	MV2	881101	96.11	148.0	89.00	63.91	16.59	0.6280	269.9	26593	1.830	1.026	4.960
798030	MV3	881101	87.30	130.9	62.67	50.43	17.54	0.4170	195.0	19728	1.060	0.0000	4.340
798031	MV4	881101	115.4	167.2	76.26	62.09	23.43	0.4800	253.0	26443	1.170	0.0000	4.480
798032	MV5	881101	114.1	162.8	79.54	62.71	23.11	0.4760	237.0	25219	1.250	0.0000	3.720
798033	PC1	890209	202.1	259.1	102.4	112.8	32.46	1.835	251.8	26483	2.910	0.0000	5.150
798034	PC2	890209	223.8	263.0	104.8	122.9	31.00	2.061	238.4	24910	3.110	0.0000	8.463
798035	PC3	890209	217.9	253.2	102.3	133.2	30.38	1.676	235.4	25045	2.830	0.0000	8.570
798036	PC4	890209	123.2	171.7	61.47	68.79	20.53	1.129	174.0	16930	1.880	0.0000	5.850
798037	PC5	890209	198.1	238.2	101.0	107.1	29.18	1.576	241.1	25314	2.460	0.0000	8.780

TABLE F-2. TRACE METAL CONCENTRATIONS (PPM DRY WT) IN INTERTIDAL SEDIMENTS

Sampnum	Stat	Date	Cu	Zn	Cr	Pb	Ni	Cd	Mn	Fe	Ag	Hg	As
798038	AH12	881221	24.33	79.34	13.4	19.02	9.980	0.4120	95.92	11536	0.2600	0.0000	2.420
798039	AH13	881223	8.430	43.33	5.880	5.630	5.260	0.0000	56.79	84342	0.0000	0.0160	1.400
798040	AH14	881223	519.2	2828.	57.07	275.5	101.9	0.4920	493.8	56658	0.2500	0.0000	10.64
798041	MP1	890103	2.050	12.92	2.160	1.800	2.770	0.0000	49.35	31940	0.0200	0.0000	0.5100
798042	MP2	890103	4.030	15.48	5.060	3.850	2.950	0.0000	34.24	3377	0.0600	0.0180	0.7700
798043	MP3	890103	11.94	34.01	10.40	11.28	6.390	0.1500	59.37	7217	0.1400	0.0370	2.140
798044	CC1	881222	12.45	28.25	10.43	7.730	6.387	0.1420	67.41	5961	0.0867	0.0000	1.227
798145	FDA	890419	12.05	38.09	9.090	9.000	6.103	0.0443	72.95	8577	0.1300	0.0260	2.223

TABLE F-3. TRACE METAL CONCENTRATIONS (PPM DRY WT) IN MERCENARIA MERCENARIA

Sampnum	Stat	Date	Cu	Zn	Cr	Pb	Ni	Cd	Mn	Fe	Ag	Hg	As
798056	AH8	881109	29.36	127.7	0.6600	1.300	11.55	1.000	43.11	288.7	0.7900	0.0000	6.030
798057	AH3	881109	20.38	123.5	0.1033	2.337	5.646	0.8923	45.53	238.5	1.187	0.0620	1.767
798058	AH2	881109	16.88	69.99	0.1266	2.237	4.187	0.5757	62.37	219.7	0.9366	0.0573	1.940
798062	AH5	881109	26.32	130.3	0.2900	0.8700	11.03	0.8730	31.24	158.7	1.000	0.0000	5.640
798063	AH10	881109	18.59	132.1	0.1900	1.500	6.820	0.6070	57.64	164.6	1.020	0.0000	4.670
798074	NJ1	881109	14.55	159.9	0.4700	1.700	10.61	0.9520	153.4	166.9	1.710	0.0000	7.600
798075	NJ2	881109	16.28	114.4	1.370	0.4800	11.98	0.7050	46.85	126.9	1.210	0.0000	14.36
798076	NJ3	881109	12.09	106.2	0.5600	0.9600	12.09	0.6720	51.42	132.3	0.9100	0.0000	9.130
798077	NJ4	881109	13.74	112.7	2.130	1.480	22.21	0.8780	64.92	148.0	1.450	0.0000	14.47
798078	NJ5	881109	12.20	110.1	0.6500	0.9000	11.42	0.6250	73.00	125.5	2.460	0.0000	9.680
798079	GB1	881109	16.65	128.4	0.9000	0.8000	9.550	0.4030	104.7	73.79	0.5400	0.0000	8.030
798080	GB2	881109	16.42	144.7	0.7633	0.9967	14.30	0.6370	103.5	58.54	0.7767	0.0000	6.160
798081	GB3	881109	17.80	145.4	0.7300	0.6900	16.77	0.6900	59.55	77.98	0.7000	0.0000	8.910
798082	GB4	881109	17.27	139.5	0.5100	1.100	11.47	0.7110	73.77	65.63	0.8100	0.0000	8.500
798083	GB5	881109	15.76	128.4	1.017	0.7033	10.46	0.4633	68.64	70.88	0.8167	0.0000	9.303
798084	MV1	881109	11.34	122.5	0.5566	1.727	10.95	0.4070	40.41	172.9	0.5333	0.0357	2.280
798085	MV2	881109	12.81	87.37	0.6900	2.490	7.013	0.3370	55.52	160.6	0.5025	0.0685	4.018
798086	MV3	881109	16.28	118.2	0.6700	1.060	13.28	0.4590	30.96	151.8	0.8500	0.0000	8.530
798087	MV4	881109	19.83	143.8	0.7600	1.190	15.14	0.5260	38.80	135.2	0.8200	0.0000	10.20
798088	MV5	881109	20.46	151.0	0.6300	1.280	16.45	0.5830	77.08	120.4	0.9200	0.0000	8.380
798089	PC1	881109	21.11	104.2	0.4200	2.390	9.180	0.5340	29.08	100.7	0.8200	0.0000	5.460
798090	PC2	881109	21.12	100.0	0.5000	2.360	9.180	0.6420	25.08	112.4	1.290	0.0000	6.150
798091	PC3	881109	25.13	111.6	0.5100	2.620	11.68	0.7620	38.07	97.19	0.8900	0.0000	5.490
798092	PC4	881109	23.10	102.9	0.5400	2.780	10.59	0.6960	40.19	109.4	0.9600	0.0000	5.080
798093	PC5	881109	19.33	113.5	0.6800	1.870	13.05	0.6850	44.63	112.7	0.8800	0.0000	6.320

TABLE F-4. TRACE METAL CONCENTRATIONS (PPM DRY WT) IN MYA ARENARIA

Sampnum	Stat	Date	Cu	Zn	Cr	Pb	Ni	Cd	Mn	Fe	Ag	Hg	As
798047	AH13	881221	13.65	80.76	0.3800	0.8000	2.000	0.5770	4.500	364.6	1.950	0.0870	5.050
798048	AH14	881223	23.26	100.9	2.050	2.680	3.180	0.3680	13.63	2421	1.580	0.0000	4.110
798049	AH12	881223	50.02	173.0	2.930	12.54	5.810	0.5030	26.95	4859	1.100	0.0000	5.380
798050	MP1	890103	22.02	79.75	0.6500	1.020	2.640	0.2660	11.84	365.5	2.570	0.0780	3.740
798051	MP2	890103	28.13	96.59	0.9200	1.970	2.050	0.3150	8.550	423.1	1.810	0.0000	3.620
798052	MP3	890103	25.03	66.24	1.100	1.490	1.670	0.3420	14.23	1004	2.740	0.0500	3.300
798053	CC1	881222	20.59	85.05	2.090	3.400	3.580	0.2490	15.89	1007	1.720	0.0000	3.440
798100	FDA	890104	15.68	85.96	0.7000	0.6233	2.263	0.4290	7.877	318.4	1.373	0.0000	4.530

TABLE F-5.   TRACE METAL CONCENTRATIONS (PPM DRY WT) IN DEPLOYED MYTILUS EDULIS

Sampnum	Stat	Date	Cu	Zn	Cr	Pb	Ni	Cd	Mn	Fe	Ag	Hg	As
798146	AH5	890606	10.78	96.45	0.7200	2.940	2.120	1.082	17.18	322.2	0.1400	0.000	3.430
798148	AH5	890606	10.41	120.8	2.403	3.203	4.417	1.213	18.12	303.3	0.1367	0.000	2.077
798150	MV1	890606	11.26	149.6	2.370	6.010	4.050	2.004	16.55	528.2	0.1400	0.000	3.050
798152	MV1	890606	11.60	192.3	2.340	7.590	5.440	2.236	16.35	566.0	0.1400	0.000	3.380
798154	TTN2	890606	10.83	184.0	3.830	5.610	7.060	1.612	22.75	538.6	0.0900	0.000	2.770
798156	TTN2	890606	10.03	93.49	1.680	3.430	3.140	0.9380	15.82	359.6	0.0900	0.000	2.710
798158	LAB	890606	7.410	98.75	0.9000	3.310	2.020	0.9480	10.40	296.3	0.0900	0.000	3.700
798160	LAB	890606	8.020	92.10	0.7900	3.560	2.010	1.052	9.570	269.4	0.1100	0.000	3.390

TABLE F-6.   TRACE METAL CONCENTRATIONS (PPM DRY WT) IN CRASSOSTREA VIRGINICA

Sampnum	Stat	Date	Cu	Zn	Cr	Pb	Ni	Cd	Mn	Fe	Ag	Hg	As
798094	AHLN	881212	704.4	3060	0.3500	1.780	1.640	4.319	9.010	490.6	4.970	nm	1.710
798095	AHLW	881212	793.1	4059	0.4000	1.380	1.650	4.849	9.390	852.8	0.7000	nm	2.690
798096	AHLM	881212	368.2	4348	0.2900	0.9000	3.550	2.888	6.120	838.4	0.4000	nm	3.160
798097	PI	881212	140.3	3009	0.3200	0.5900	2.420	1.849	6.530	96.55	0.7300	nm	3.730
798098	PI	881212	147.0	3403	0.4300	0.6800	4.320	1.966	8.980	113.1	0.6900	nm	4.160
798099	PI	881212	132.1	3162	0.4500	1.030	2.790	1.674	7.520	112.2	0.7400	nm	3.460

TABLE F-7. TRACE METAL CONCENTRATIONS (PPM DRY WT) IN NEPHTYS INCISA

Sampnum	Stat	Date	Cu	Zn	Cr	Pb	Ni	Cd	Mn	Fe	Ag	Hg	As
798106	AH2	890214	23.21	184.4	0.17	6.87	2.94	0.580	8.12	736.8	nm	nm	nm
798107	AH2	890214	32.77	181.0	0.54	6.84	3.04	0.411	8.66	877.7	nm	nm	nm
798108	MV3	890214	42.75	205.1	0.19	9.80	4.87	0.926	12.69	928.8	nm	nm	nm
798109	MV3	890214	10.64	232.3	0.18	8.61	5.37	0.926	11.94	1033.	nm	nm	nm
798110	MV3	890214	26.12	208.7	0.50	10.9	4.43	0.750	12.75	982.8	nm	nm	nm

TABLE F-7. TRACE METAL CONCENTRATIONS (PPB) IN SEEP SAMPLES

Sampnum	Stat	Date	Cu	Zn	Cr	Pb	Ni	Cd	Mn	Fe	Ag	As
798196	LANDN	890802	14.8	285	0.267	57.5	34.4	4.51	144	2430	0.510	0.00
798197	LANDN	890802	10.0	37.0	1.25	38.0	99.5	0.776	219	1120	0.457	0.00
798198	LANDN	890802	111	280	0.00	14.7	51.1	4.76	20.6	469	107	0.00
798199	LANDN	890802	22.5	66.0	0.00	12.1	59.0	2.53	48.5	220	2.36	0.00
798200	LANDN	890802	46.6	219	0.00	17.0	75.3	6.54	71.2	387	6.19	0.00
798201	LANDN	890802	49.8	643	0.00	54.5	75.7	15.6	43.6	254	3.29	5.95
798202	LANDN	890802	21.8	0.00	0.00	7.20	6.12	2.09	64.0	942	0.00	0.00
798203	LANDN	890802	31.4	18.0	0.00	15.4	55.1	0.881	214	4020	0.00	0.00
798204	LANDN	890802	3.79	0.00	0.00	0.00	4.47	0.00	85.4	876	0.00	0.00
798205	LANDN	890802	7.74	170	0.00	0.00	3.60	0.00	20.3	671	0.00	0.00

APPENDIX G

PESTICIDE CONCENTRATIONS*

TABLE G-1. PESTICIDE CONCENTRATIONS (PPB DRY WT) IN SUBTIDAL SEDIMENTS

Sampnum	Station	Date	alpha-BHC	gamma-BHC	alpha-Chlordane	gamma-Chlordane	DDD	DDT	DDE	HCB
798000	AH8	881031	0.000	0.000	1.32	1.08	4.03	0.683	3.27	0.230
798001	AH3	881031	0.000	0.000	1.70	1.05	6.38	8.29	37.63	3.03
798002	AH2	881103	0.000	0.000	7.36	5.89	23.3	47.4	31.73	5.16
798006	AH5	881103	0.000	0.000	0.479	0.492	1.78	0.944	1.57	0.144
798007	AH10	890209	0.000	0.000	0.522	0.502	1.73	0.619	2.00	5.43
798018	NJ1	881031	0.000	0.000	0.160	0.204	0.683	0.434	1.17	0.056
798019	NJ2	881031	0.000	0.162	0.000	0.233	0.543	0.362	0.597	0.027
798020	NJ3	881101	0.000	0.000	0.000	0.146	0.293	0.228	0.308	0.012
798021	NJ4	881101	0.000	0.000	0.054	0.000	0.191	0.107	0.370	0.019
798022	NJ5	881101	0.000	0.000	0.000	0.000	0.291	0.400	0.499	0.008
798023	GB1	881031	0.000	0.000	0.000	0.000	0.197	0.159	0.244	0.030
798024	GB2	881031	0.000	0.000	0.000	0.000	0.000	0.000	0.195	0.018
798025	GB3	881031	0.000	0.000	0.000	0.000	0.000	0.000	0.121	0.000
798026	GB4	881031	0.000	0.000	0.000	0.143	0.467	0.000	0.550	0.022
798027	GB5	881031	0.000	0.000	0.000	0.000	0.000	0.000	0.145	0.000
798028	MV1	881101	1.42	2.96	67.8	1.70	20.8	5.31	14.55	0.493
798029	MV2	881101	0.000	4.10	7.57	12.3	0.000	38.6	11.62	0.000
798030	MV3	881101	0.000	0.000	0.506	0.429	1.05	0.175	2.73	0.086
798031	MV4	881101	0.000	0.000	0.598	0.555	1.42	0.437	4.45	0.107
798032	MV5	881101	0.000	0.000	0.564	0.656	1.29	0.575	3.24	0.093
798033	PC1	890209	0.000	0.000	1.16	0.962	2.44	0.000	6.13	0.227
798034	PC2	890209	0.000	0.088	6.00	0.973	3.29	0.492	5.20	0.437
798035	PC3	890209	0.000	0.000	0.000	0.940	4.20	0.578	6.40	0.201
798036	PC4	890209	0.000	0.000	7.000	0.526	1.68	0.336	4.24	0.572
798037	PC5	890209	0.000	0.000	0.000	0.985	2.73	0.373	5.34	0.191

TABLE G-2. PESTICIDE CONCENTRATIONS (PPB DRY WT) IN INTERTIDAL SEDIMENTS

Sampnum	Station	Date	alpha-BHC	gamma-BHC	alpha-Chlordane	gamma-Chlordane	DDD	DDT	DDE	HCB
798038	AH12	881221	0.000	0.000	0.000	0.321	22.7	0.209	1.34	0.504
798040	AH14	881223	0.000	0.000	0.000	0.000	26.4	0.230	1.06	0.251
798041	MP1	890103	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012
798044	CC1	881222	0.055	0.000	6.000	0.092	4.99	0.237	0.207	0.026

TABLE G-3. PESTICIDE CONCENTRATIONS (PPB DRY WT) IN MERCENARIA MERCENARIA

Sampnum	Station	Date	alpha-BHC	gamma-BHC	alpha-Chlordane	gamma-Chlordane	DDD	DDT	DDE	HCB
798056	AH8	881109	0.000	0.000	0.000	1.77	0.000	0.000	0.000	0.000
798057	AH3	881109	0.000	0.000	2.56	3.29	2.14	1.53	5.86	0.789
798058	AH2	881109	0.000	0.000	1.75	2.85	3.79	0.000	5.03	0.667
798062	AH5	881109	0.000	0.000	0.000	0.000	0.000	0.000	3.16	0.656
798063	AH10	881109	0.000	0.000	0.000	1.49	0.000	0.000	0.000	0.000
798074	NJ1	881109	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
798075	NJ2	881109	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
798076	NJ3	881109	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
798077	NJ4	881109	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
798078	NJ5	881109	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
798079	GB1	881109	0.000	0.000	1.79	2.81	0.000	0.000	0.000	0.000
798080	GB2	881109	0.000	0.000	1.41	2.39	2.35	0.000	0.000	0.000
798084	MV1	881109	0.520	0.000	1.95	2.15	1.28	0.000	4.20	0.610
798085	MV2	881109	0.590	0.000	1.48	1.67	1.37	0.000	4.17	0.900
798088	MV5	881109	0.000	0.000	1.74	2.32	0.000	0.000	5.29	0.650
798089	PC1	881109	0.000	0.000	1.90	2.39	0.000	0.000	4.47	0.400
798090	PC2	881109	0.000	0.000	0.000	2.12	0.000	0.000	0.000	0.000
798091	PC3	881109	0.000	0.000	1.67	2.37	0.000	0.000	0.000	0.000
798092	PC4	881109	0.000	0.000	1.79	2.30	0.000	0.000	4.10	0.530
798093	PC5	881109	0.000	0.000	2.02	2.51	0.000	0.000	4.72	0.520

TABLE G-4. PESTICIDE CONCENTRATIONS (PPB DRY WT) IN MYA ARENARIA

Sampnum	Station	Date	alpha-BHC	gamma-BHC	alpha-Chlordane	gamma-Chlordane	DDD	DDT	DDE	HCB
798048	AH13	881223	0.584	0.304	1.00	2.10	56.2	1.49	2.40	0.473
798049	AH14	881223	0.515	0.322	0.000	1.79	38.5	0.000	4.14	0.573
798051	MP12	890103	0.659	0.634	4.00	2.81	46.8	0.000	1.27	0.340
798053	CC1	881222	0.622	0.585	0.000	2.73	32.6	0.000	2.41	0.448
798054	CC2	881222	0.659	0.680	0.000	2.40	27.0	0.000	3.44	0.922

TABLE G-7. DISSOLVED PESTICIDE CONCENTRATIONS (UG/L) IN WATER SAMPLES

Sampnum	Station	Date	alpha- BHC	gamma- BHC	alpha- Chlordane	gamma- Chlordane	DDD	DDT	DDE	HCB
798209	AH2	890802	0.00027	0.00007	0.00000	0.00000	0.00001	0.00000	0.00000	0.00003
798210	AH2	890802	0.00031	0.00008	0.00007	0.00000	0.00002	0.00000	0.00000	0.00003
798211	MV1	890802	0.00033	0.00011	0.00000	0.00000	0.00002	0.00000	0.00000	0.00002
798212	MV1	890802	0.00038	0.00008	0.00000	0.00000	0.00001	0.00000	0.00000	0.00002

TABLE G-8. PARTICULATE PESTICIDE CONCENTRATIONS (PPB) IN WATER SAMPLES

Sampnum	Station	Date	alpha- BHC	gamma- BHC	alpha- Chlordane	gamma- Chlordane	DDD	DDT	DDE	HCB
798209	AH2	890802	0.00000	0.00000	0.00002	0.00000	0.00003	0.00000	0.00000	0.00000
798210	AH2	890802	0.00000	0.00000	0.00000	0.00000	0.00004	0.00000	0.00000	0.00000
798211	MV1	890802	0.00000	0.00000	0.00000	0.00000	0.00004	0.00000	0.00000	0.00000
798212	MV1	890802	0.00000	0.00000	0.00000	0.00000	0.00004	0.00000	0.00000	0.00000

TABLE G-9. PESTICIDE CONCENTRATIONS (UG/L) IN SEEP SAMPLES

Sampnum	Station	Date	alpha- BHC	gamma- BHC	alpha- Chlordane	gamma- Chlordane	DDD	DDT	DDE	HCB
798264	LANDS	890927	0.00000	0.00000	0.00350	0.00000	0.00416	0.03500	0.00000	0.00015
798265	LANDS	890927	0.00000	0.00000	0.01700	0.00813	0.01547	0.40300	0.48900	0.00000

TABLE G-10.   PESTICIDE CONCENTRATIONS (UG/L) IN GROUND WATER SAMPLES

Sampnum	Station	Date	alpha-BHC	gamma-BHC	alpha-Chlordane	gamma-Chlordane	DDD	DDT	DDE	HCB
798279	LND	891116	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
798280	LND	891116	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.01060	0.00000
798281	LND	891116	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
798282	LND	891116	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

TABLE G-5. PESTICIDE CONCENTRATIONS (PPB DRY WT) IN MYTILUS EDULIS

Sampnum	Station	Date	alpha-BHC	gamma-BHC	alpha-Chlordane	gamma-Chlordane	DDD	DDT	DDE	HCB
798146	AH5	890606	1.48	0.586	0.000	10.6	16.7	3.76	16.2	0.731
798148	AH5	890606	1.18	0.668	8.56	9.52	16.6	3.38	13.2	0.845
798150	MV1	890606	0.972	0.661	8.48	8.88	10.7	0.000	14.2	0.432
798152	MV1	890606	0.000	0.595	8.77	9.24	14.2	2.78	10.7	0.318
798154	TTN2	890606	0.710	0.425	6.75	6.98	9.55	1.88	10.2	0.346
798156	TTN2	890606	1.10	0.672	8.69	9.05	13.1	2.24	12.4	0.547
798158	LAB	890606	1.16	0.511	6.39	7.06	9.48	3.01	8.78	0.500
798161	LAB	890606	0.490	0.411	6.09	6.68	9.18	3.05	11.8	0.500

TABLE G-6. PESTICIDE CONCENTRATIONS (PPB DRY WT) IN CRASSOSTREA VIRGINICA

Sampnum	Station	Date	alpha-BHC	gamma-BHC	alpha-Chlordane	gamma-Chlordane	DDD	DDT	DDE	HCB
798094	AHLN	881212	0.851	0.524	11.3	12.1	8.18	31.4	27.0	0.204
798095	AHLW	881212	0.996	0.754	9.74	9.76	5.02	32.8	37.0	0.000
798096	AHLM	881212	0.933	0.662	12.4	13.2	1.56	29.4	27.2	0.000
798097	PI	881212	1.03	0.690	5.22	5.70	0.000	10.0	5.61	0.000
798098	PI	881212	1.09	0.640	6.05	6.94	0.000	4.81	7.17	0.000
798099	PI	881212	0.917	0.339	3.86	4.58	0.000	23.9	4.03	0.000

APPENDIX H

POLYCHLORINATED BIPHENYL CONCENTRATIONS*

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* The following chemical concentration data are organized by sample matrix. Individual field replicates are identified by unique sample numbers (SAMPNUM). Instrumental replicates are identified by REP. Station designations follow the terminology described in the main body of this report. Sample collection dates follow the format YYMMDD. All contaminant abbreviations and acronyms are described in the text.

Entries of "0.00" or "nd" indicate contaminant levels below analytical detection limits, rather than actual zero concentrations. Entries of "nm" indicate the contaminant not to have been measured in that sample.

TABLE H-1.   POLYCHLORINATED BIPHENYL CONCENTRATIONS
             (PPB DRY WT) IN SUBTIDAL SEDIMENTS

Sampnum	Station	Date	Aroclor 1242	Aroclor 1254	Total PCB
798000	AH8	881031	0.000	505	505
798001	AH3	881031	1.17	497	498
798002	AH2	881103	0.000	182	182
798006	AH5	881103	0.000	204	204
798007	AH10	890209	0.000	202	202
798018	NJ1	881031	0.000	126	126
798019	NJ2	881031	0.000	42.6	42.6
798020	NJ3	881101	0.000	47.1	47.1
798027	GB5	881031	0.000	48.7	48.7
798028	MV1	881101	0.000	132	132
798029	MV2	881101	0.000	94.9	94.9
798030	MV3	881101	0.000	221	221
798031	MV4	881101	0.000	284	284
798032	MV5	881101	0.000	233	233
798033	PC1	890209	0.000	348	348

TABLE H-2.   POLYCHLORINATED BIPHENYL CONCENTRATIONS
             (PPB DRY WT) IN INTERTIDAL SEDIMENTS

Sampnum	Station	Date	Aroclor 1242	Aroclor 1254	Total PCB
798039	AH13	881223	0.000	7.93	7.93
798042	MP2	890103	0.000	3.09	3.09
798043	MP3	890103	0.000	14.1	14.1
798145	FDA	890419	0.000	22.1	22.1

TABLE H-3.   POLYCHLORINATED BIPHENYL CONCENTRATIONS
             (PPB DRY WT) IN MERCENARIA MERCENARIA

Sampnum	Station	Date	Aroclor 1242	Aroclor 1254	Total PCB
798056	AH8	881109	0.00	249	249
798057	AH3	881109	0.00	204	204
798058	AH2	881109	0.00	149	149
798062	AH5	881109	0.00	376	376
798063	AH10	881109	0.00	235	235
798074	NJ1	881109	0.00	125	125
798075	NJ2	881109	0.00	99.8	99.8
798076	NJ3	881109	0.00	54.8	54.8
798077	NJ4	881109	0.00	61.3	61.3
798078	NJ5	881109	0.00	78.1	78.1
798079	GB1	881109	0.00	149	149
798080	GB2	881109	0.00	135	135
798084	MV1	881109	0.00	71.4	71.4
798085	MV2	881109	0.00	88.6	88.6
798088	MV5	881109	0.00	315	315
798089	PC1	881109	0.00	233	233
798090	PC2	881109	0.00	141	141
798091	PC3	881109	0.00	184	184
798092	PC4	881109	0.00	227	227
798093	PC5	881109	0.00	275	275

TABLE H-4.   POLYCHLORINATED BIPHENYL CONCENTRATIONS
             (PPB DRY WT) IN MYA ARENARIA

Sampnum	Station	Date	Aroclor 1242	Aroclor 1254	Total PCB
798047	AH13	881221	0.00	150	150
798050	MP1	890103	5.22	164	169
798052	MP3	890103	7.34	107	115
798100	FDA	890104	0.00	248	248

TABLE H-5. POLYCHLORINATED BIPHENYL CONCENTRATIONS
(PPB DRY WT) IN MYTILUS EDULIS

Sampnum	Station	Date	Aroclor 1242	Aroclor 1254	Total PCB
798146	AH5	890606	54.2	1170	1220
798148	AH5	890606	55.7	973	1030
798150	MV1	890606	22.7	1050	1070
798152	MV1	890606	15.1	760	775
798154	TTN2	890606	25.4	789	814
798156	TTN2	890606	43.4	1030	1070
798158	LAB	890606	33.4	927	961
798161	LAB	890606	35.6	1040	1070

TABLE H-6. POLYCHLORINATED BIPHENYL CONCENTRATIONS
(PPB DRY WT) IN CRASSOSTREA VIRGINICA

Sampnum	Station	Date	Aroclor 1242	Aroclor 1254	Total PCB
798094	AHLN	881212	30.2	1260	1290
798095	AHLW	881212	60.0	1420	1480
798096	AHLM	881212	47.8	1600	1650
798097	PI	881212	0.0	572	572
798098	PI	881212	19.0	705	705
798099	PI	881212	32.9	508	541

TABLE H-7.   DISSOLVED POLYCHLORINATED BIPHENYL
CONCENTRATIONS (UG/L) IN WATER SAMPLES

Sampnum	Station	Date	Aroclor 1242	Aroclor 1254	Total PCB
798209	AH2	890802	nd	nd	nd
798210	AH2	890802	nd	nd	nd
798211	MV1	890802	nd	nd	nd
798212	MV1	890802	nd	nd	nd

TABLE H-8.   PARTICULATE POLYCHLORINATED BIPHENYL
CONCENTRATIONS (PPB) IN WATER SAMPLES

Sampnum	Station	Date	Aroclor 1242	Aroclor 1254	Total PCB
798209	AH2	890802	nd	0.002	0.002
798210	AH2	890802	nd	0.002	0.002
798211	MV1	890802	nd	nd	nd
798212	MV1	890802	nd	0.001	0.001

TABLE H-9.   POLYCHLORINATED BIPHENYL CONCENTRATIONS
(UG/L) IN LANDFILL SEEP SAMPLES

Sampnum	Station	Date	Aroclor 1242	Aroclor 1254	Total PCB
798264	LANDS	890927	nd	0.391	0.391
798265	LANDS	890927	0.005	1.49	1.49

TABLE H-10. POLYCHLORINATED BIPHENYL CONCENTRATIONS
            (UG/L) IN LANDFILL GROUND WATER SAMPLES

Sampnum	Station	Date	Aroclor 1242	Aroclor 1254	Total PCB
798279	LND	891116	nd	0.010	0.010
798280	LND	891116	nd	0.046	0.046
798281	LND	891116	nd	0.021	0.021
798282	LND	891116	nd	0.018	0.018

APPENDIX I

POLYCYCLIC AROMATIC

HYDROCARBON CONCENTRATIONS*

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* The following chemical concentration data are organized by sample matrix. Individual field replicates are identified by unique sample numbers (SAMPNUM). Instrumental replicates are identified by REP. Station designations follow the terminology described in the main body of this report. Sample collection dates follow the format YYMMDD. All contaminant abbreviations and acronyms are described in the text.

Entries of "0.0" or "nd" indicate contaminant levels below analytical detection limits, rather than actual zero concentrations. Entries of "nm" indicate the contaminant not to have been measured in that sample.

TABLE I-1.   POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB DRY WT) IN SUBTIDAL SEDIMENTS

Compound	Sampnum Station Date	798000 AH8 881031	798001 AH3 881031	798002 AH2 881103	798006 AH5 881103	798007 AH10 890209	798018 NJ1 881031	798019 NJ2 881031	798020 NJ3 881101	798021 NJ4 881101
Fluorene		50.3	18.2	24.7	9.38	13.0	17.5	43.7	4.83	6.36
Phenanthrene		811	231	198	137	165	169	474	41.2	50.8
Anthracene		75.8	68.7	260	21.6	33.9	39.6	156	8.81	8.71
C1 Phen.+Anthra.		477	179	180	90.4	102	78.4	269	32.8	22.2
C2 Phen.+Anthra.		357	134	120	72.3	82.5	58.1	174	33.4	18.0
C3 Phen.+Anthra.		215	77.5	64.1	53.0	59.5	38.1	98.9	26.0	9.35
C4 Phen.+Anthra.		102	34.1	39.1	20.3	26.5	21.7	40.8	14.6	5.71
Fluoranthene		1510	508	604	351	427	320	909	129	107
Pyrene		1670	487	462	348	414	284	796	130	96.6
Benz[a]anthracene		447	202	253	146	147	136	373	48.9	42.3
Chrysene		818	312	398	172	250	140	352	60.2	50.8
Sum Benzofluorathenes		1710	640	637	458	499	327	759	151.0	95.4
Benzo[e]pyrene		651	271	259	167	172	119	260	54.9	36.3
Benzo[a]pyrene		631	267	269	140	165	151	409	65.1	42.8
Perylene		165	104	89.6	51.5	52.3	49.9	113	22.1	14.5
Indeno[1,2,3-cd]pyrene		600	233	271	152	146	138	339	75.0	40.9
Benzo[ghi]perylene		564	193	230	142	128	131	290	71.3	36.9
Sum MW 276 PAHs		1620	586	670	429	385	420	956	205	110
Dibenz[a,h]anthracene		187	68.3	75.3	48.6	47.5	41.1	101	18.7	13.0
Sum MW 278 PAHs		642	224	267	156	135	150	407	77.4	41.3
Coronene		159	32.1	58.6	49.0	28.8	53.6	98.8	30.4	13.4
Sum MW 302 PAHs		1010	139	245	312	275	348	768	193	94.2
10-Benzotriazole		414	711	725	273	285	155	94.1	88.1	36.0
Chloro-Benzotriazole		84.9	84.0	88.1	43.4	47.9	30.3	26	19.7	8.24

(continued)

TABLE I-1 (continued).   POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB DRY WT) IN SUBTIDAL SEDIMENTS

Compound	Sampnum Station Date	798023 GB1 881031	798024 GB2 881031	798025 GB3 881031	798026 GB4 881031	798027 GB5 881031	798028 MV1 881101	798029 MV2 881101	798030 MV3 881101	798031 MV4 881101
Fluorene		0.849	0.501	0.289	2.92	0.583	8.86	9.46	8.99	12.2
Phenanthrene		6.55	3.83	2.09	22.1	3.43	66.3	69.0	77.6	97.3
Anthracene		1.19	0.792	0.453	7.11	0.867	22.4	19.4	15.3	18.9
C1 Phen.+Anthra.		5.03	2.97	1.78	15.7	3.07	63.5	63.3	55.7	71.0
C2 Phen.+Anthra.		4.93	2.45	2.04	13.5	3.31	57.4	47.7	49.7	66.3
C3 Phen.+Anthra.		3.78	1.47	0.957	10.5	2.76	32.7	31.7	40.2	51.8
C4 Phen.+Anthra.		2.78	1.10	1.02	4.88	1.76	28.0	22.2	18.0	24.8
Fluoranthene		16.3	11.4	5.68	60.6	7.98	168	166	197	253
Pyrene		14.9	10.8	5.25	56.9	7.80	160	155	199	258
Benz[a]anthracene		6.22	4.88	2.34	28.4	3.27	68.8	65.1	80.6	106
Chrysene		9.69	6.45	3.44	46.1	4.13	93.4	97.0	106	137
Sum Benzofluorathenes		25.9	16.7	9.18	94.0	14.7	277	212	321	393
Benzo[e]pyrene		10.3	6.65	3.64	34.6	5.25	118	87.7	129	161
Benzo[a]pyrene		7.87	4.57	2.84	32.3	4.75	123	87.2	130	162
Perylene		3.12	1.87	1.12	10.5	1.59	44.8	28.9	42.9	53.1
Indeno[1,2,3-cd]pyrene		11.1	6.72	4.95	33.9	8.30	177	76.0	206	267
Benzo[ghi]perylene		10.8	6.45	4.45	29.8	7.34	161	62.4	193	245
Sum MW 276 PAHs		30.3	18.3	12.6	89.1	21.1	462	202	569	697
Dibenz[a,h]anthracene		2.91	1.62	1.24	9.05	2.27	44.9	19.9	54.3	71.2
Sum MW 278 PAHs		12.3	5.58	4.88	28.8	7.86	165	74.7	199	253
Coronene		5.25	2.5	2.23	9.33	3.64	47.3	10.6	120	165
Sum MW 302 PAHs		29.3	15.3	12.2	59.7	20.0	183	47.5	754	1050
10-Benzotriazole		56.1	17.5	9.54	114	56.0	974	1020	1120	1550
Chloro-Benzotriazole		10.6	4.51	2.66	20.6	10.0	107	107	224	295

(continued)

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TABLE I-1 (continued). POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB DRY WT) IN SUBTIDAL SEDIMENTS

Compound	Sampnum Station Date	798033 PC1 890209	798034 PC2 890209	798035 PC3 890209	798036 PC4 890209	798037 PC5 890209
Fluorene		15.1	14.4	14.3	10.1	15.8
Phenanthrene		119	123	134	82.2	117
Anthracene		31.4	23.7	27.2	16.1	29.7
C1 Phen.+Anthra.		97.0	85.2	88.4	60.1	75.3
C2 Phen.+Anthra.		90.2	75.4	75.7	55.0	62.3
C3 Phen.+Anthra.		70.9	51.1	53.3	39.6	48.3
C4 Phen.+Anthra.		41.2	29.3	33.2	18.4	26.7
Fluoranthene		345	296	317	229	282
Pyrene		353	291	336	226	290
Benz[a]anthracene		160	135	139	97.2	127
Chrysene		219	175	182	121	165
Sum Benzofluorathenes		558	463	466	305	423
Benzo[e]pyrene		215	177	177	117	175
Benzo[a]pyrene		236	188	188	130	166
Perylene		71.9	57.2	57.7	38.1	56.1
Indeno[1,2,3-cd]pyrene		338	266	259	195	229
Benzo[ghi]perylene		324	246	245	181	217
Sum MW 276 PAHs		915	700	705	522	594
Dibenz[a,h]anthracene		114	82.1	86.1	61.0	68.0
Sum MW 278 PAHs		354	258	243	196	208
Coronene		237	177	170	142	127
Sum MW 302 PAHs		1450	1050	1070	883	881
10-Benzotriazole		2810	2370	2890	1270	2640
Chloro-Benzotriazole		469	445	543	236	446

TABLE I-2. POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB DRY WT) IN INTERTIDAL SEDIMENTS

Compound	Sampnum Station Date	798038 AH12 881221	798039 AH13 881223	798040 AH14 881223	798041 MP1 890103	798042 MP2 890103	798043 MP3 890103	798044 CC1 881222	798145 FDA 890419
Fluorene		5.43	0.134	5.08	0.000	2.41	219	39.0	2.00
Phenanthrene		58.9	1.070	58.0	0.541	24.2	1640	569	21.3
Anthracene		8.62	0.334	9.39	0.145	7.85	695	119	9.29
C1 Phen.+Anthra.		28.3	0.846	46.4	0.631	18.7	870.5	281	17.3
C2 Phen.+Anthra.		23.7	1.130	49.1	0.469	10.7	289	201	18.8
C3 Phen.+Anthra.		19.2	1.330	34.2	0.788	5.20	193	105	17.9
C4 Phen.+Anthra.		11.7	0.929	14.8	0.252	1.97	58.9	42.1	9.67
Fluoranthene		139	3.760	245	1.80	29.6	1190	1630	51.9
Pyrene		123	3.320	194	1.51	26.0	941	1450	47.4
Benz[a]anthracene		46.9	1.330	48.3	0.644	14.0	485	601	17.3
Chrysene		71.7	2.640	99.7	0.929	14.7	449	578	31.5
Sum Benzofluoranthenes		161	6.050	150	1.89	24.6	611	1210	61.5
Benzo[e]pyrene		60.4	2.110	56.2	0.764	9.12	136	437	24.3
Benzo[a]pyrene		61.6	1.530	47.2	0.776	10.8	325	703	21.0
Perylene		36.2	0.544	25.1	0.275	2.94	67.1	192	8.22
Indeno[1,2,3-cd]pyrene		63.5	1.500	45.6	0.701	7.88	156	554	21.4
Benzo[ghi]perylene		59.0	1.440	43.2	0.699	7.25	129	503	21.0
Sum MW 276 PAHs		178.0	4.280	131	1.92	25.0	500	1630	62.9
Dibenz[a,h]anthracene		22.7	0.637	16.8	0.205	3.37	87.75	168	6.81
Sum MW 278 PAHs		71.2	1.560	55.5	0.585	10.3	294	542	23.3
Coronene		20.4	0.521	14.6	0.175	1.97	36.8	173	7.51
Sum MW 302 PAHs		149	1.490	108	0.668	15.2	399	1160	42.5
10-Benzotriazole		49.6	3.060	12.6	1.140	14.2	50.65	59.0	21.9
Chloro-Benzotriazole		12.5	0.579	3.07	0.297	2.14	7.12	12.7	3.73

TABLE I-3. POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB DRY WT) IN MERCENARIA MERCENARIA

Compound	Sampnum Station Date	798056 AH8 881109	798057 AH3 881109	798058 AH2 881109	798062 AH5 881109	798063 AH10 881109	798074 NJ1 881109	798075 NJ2 881109	798076 NJ3 881109	798077 NJ4 881109
Fluorene		4.61	5.17	4.74	3.75	3.08	1.05	1.05	22.0	1.25
Phenanthrene		27.2	13.2	15.6	10.4	17.9	4.13	3.69	223	5.51
Anthracene		5.13	8.17	5.85	3.39	4.68	0.811	0.707	52.4	0.706
C1 Phen.+Anthra.		27.9	33.4	31.3	24.6	37.7	7.91	8.13	103	8.06
C2 Phen.+Anthra.		53.4	84.8	64.0	61.5	91.5	18.0	17.2	67.0	17.8
C3 Phen.+Anthra.		38.2	80.2	36.2	37.3	62.5	12.0	11.7	29.7	13.2
C4 Phen.+Anthra.		11.1	25.3	13.8	11.0	21.0	5.33	5.74	7.56	6.07
Fluoranthene		307	250	214	226	276	45.3	46.5	440	35.2
Pyrene		264	174	153	162	207	32.7	31.8	306	24.7
Benz[a]anthracene		40.0	35.0	27.6	15.1	25.1	3.80	4.73	169	4.42
Chrysene		48.5	39.7	31.9	29.0	40.3	8.12	8.47	105	8.45
Sum Benzofluorathenes		48.4	37.7	37.1	16.7	28.3	7.95	7.51	234	11.7
Benzo[e]pyrene		24.0	8.49	10.0	11.7	19.0	5.99	6.01	82.8	8.53
Benzo[a]pyrene		8.43	1.81	3.54	3.14	4.72	1.66	1.17	98.2	3.46
Perylene		3.14	4.02	2.39	2.73	4.21	1.35	0.927	28.7	2.81
Indeno[1,2,3-cd]pyrene		7.80	3.53	5.07	2.05	3.96	1.75	1.50	68.7	3.87
Benzo[ghi]perylene		9.15	4.81	5.92	3.75	5.98	2.96	2.61	57.5	6.16
Sum MW 276 PAHs		24.5	16.2	21.8	7.30	13.2	6.59	5.10	229	13.9
Dibenz[a,h]anthracene		2.05	1.82	1.79	0.582	0.956	0.486	0.294	22.1	0.80
Sum MW 278 PAHs		10.4	13.6	7.39	3.88	4.68	2.79	2.18	94.4	6.05
Coronene		2.06	3.20	1.85	1.04	1.55	0.48	0.387	17.4	1.00
Sum MW 302 PAHs		9.58	8.60	12.4	3.28	5.28	2.23	2.70	154	8.45
10-Benzotriazole		51.6	144	143	87.1	74.1	44.5	98.9	69.3	64
Chloro-Benzotriazole		13.1	16.5	19.5	14.5	17.0	10.6	17.5	12.1	14.8

(continued)

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TABLE I-3 (continued).   POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB DRY WT) IN MERCENARIA MERCENARIA

Compound	Sampnum Station Date	798079 GB1 881109	798080 GB2 881109	798081 GB3 881109	798082 GB4 881109	798083 GB5 881109	798084 MV1 881109	798085 MV2 881109	798086 MV3 881109	798087 MV4 881109
Fluorene		1.46	2.21	1.63	1.91	1.65	1.15	1.44	2.82	3.35
Phenanthrene		3.64	4.54	4.41	3.92	4.63	4.55	5.85	7.35	7.94
Anthracene		1.12	1.28	1.27	1.15	1.02	2.23	2.46	2.34	2.71
C1 Phen.+Anthra.		12.2	10.4	9.49	10.7	9.69	15.0	21.0	18.0	17.5
C2 Phen.+Anthra.		35.9	26.3	25.4	28.1	25.1	42.4	57.2	53.8	46.5
C3 Phen.+Anthra.		26.5	17.3	18.3	19.2	16.7	29.9	36.6	34.2	30.0
C4 Phen.+Anthra.		5.89	4.08	5.12	5.78	4.65	11.6	16.4	10.8	10.7
Fluoranthene		77.9	66.0	57.7	66.2	66.8	79.9	94.3	137	117
Pyrene		56.0	45.9	44.0	48.3	46.0	62.6	72.4	99.8	92.6
Benz[a]anthracene		4.28	7.49	2.92	7.10	6.40	9.65	8.64	12.8	12.4
Chrysene		11.2	7.53	9.59	9.82	9.38	13.2	18.2	21.5	21.0
Sum Benzofluoranthenes		8.11	6.30	6.51	8.46	8.11	23.3	24.8	16.4	19.2
Benzo[e]pyrene		7.69	6.32	6.46	7.16	6.61	6.44	7.81	10.7	11.5
Benzo[a]pyrene		1.38	0.931	1.48	1.06	0.88	1.94	3.19	3.05	5.19
Perylene		1.07	0.509	0.913	1.17	0.82	1.08	1.83	2.11	2.18
Indeno[1,2,3-cd]pyrene		1.75	1.18	1.42	1.33	1.37	2.63	3.85	2.72	3.62
Benzo[ghi]perylene		3.23	2.31	2.68	3.00	2.64	3.63	5.47	4.61	5.35
Sum MW 276 PAHs		6.54	4.63	5.67	5.73	5.96	8.82	13.4	17.6	12.1
Dibenz[a,h]anthracene		0.348	0.315	0.278	0.246	0.230	0.451	0.840	0.841	1.42
Sum MW 278 PAHs		2.01	1.59	2.18	1.99	2.05	1.93	3.32	6.05	5.84
Coronene		0.589	0.390	0.643	0.519	0.507	0.627	1.86	1.01	1.88
Sum MW 302 PAHs		3.12	2.32	2.94	1.82	2.44	3.52	4.94	4.78	2.97
10-Benzotriazole		302	176	200	353	300	183	109	290	206.0
Chloro-Benzotriazole		49.9	32.6	30.3	52.2	50.6	21.9	21.9	45.3	37.4

(continued)

TABLE I-3 (continued). POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB DRY WT) IN MERCENARIA MERCENARIA

| Compound | Sampnum | 798089 | 798090 | 798091 | 798092 | 798093 |
| | Station | PC1 | PC2 | PC3 | PC4 | PC5 |
	Date	881109	881109	881109	881109	881109
Fluorene		1.61	1.90	1.83	0.922	0.787
Phenanthrene		4.05	5.28	6.22	4.46	5.66
Anthracene		0.952	1.38	1.57	1.17	1.51
C1 Phen.+Anthra.		11.5	12.3	11.8	12.1	15.6
C2 Phen.+Anthra.		21.2	23.6	20.9	23.3	35.6
C3 Phen.+Anthra.		16.5	16.2	15.0	16.9	31.7
C4 Phen.+Anthra.		8.81	8.5	6.71	6.67	15.9
Fluoranthene		55.7	62.7	51.9	57.2	77.0
Pyrene		56.7	55.9	50.9	52.7	82.1
Benz[a]anthracene		7.55	5.15	7.13	6.67	10.8
Chrysene		15.5	15.0	12.5	12.0	15.6
Sum Benzofluorathenes		15.0	10.8	11.6	10.7	19.4
Benzo[e]pyrene		13.7	7.96	11.6	10.7	16.7
Benzo[a]pyrene		2.27	2.76	2.21	2.15	4.05
Perylene		1.85	1.35	1.97	2.24	3.54
Indeno[1,2,3-cd]pyrene		3.10	2.17	2.12	2.05	3.41
Benzo[ghi]perylene		5.45	3.45	4.01	4.40	6.61
Sum MW 276 PAHs		10.7	8.91	7.67	9.24	14.6
Dibenz[a,h]anthracene		0.511	3.77	0.644	0.465	0.80
Sum MW 278 PAHs		4.51	0.554	2.77	3.22	6.52
Coronene		1.09	0.886	0.624	0.867	1.00
Sum MW 302 PAHs		3.93	3.58	2.1	3.96	5.21
10-Benzotriazole		155	179	187	184	243
Chloro-Benzotriazole		31.3	29.0	37.5	38.7	49.0

TABLE I-4.   POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB DRY WT) IN MYA ARENARIA

Compound	Sampnum	798047 AH13 881221	798048 AH14 881223	798049 AH12 881223	798050 MP1 890103	798051 MP2 890103	798052 MP3 890103	798053 CC1 881222	798054 CC2 881222	798100 PDA 890104
	Station									
	Date									
Fluorene		4.15	11.6	4.82	9.24	9.03	8.73	3.48	4.18	12.2
Phenanthrene		18.7	57.6	43.6	39.3	42.1	42.3	14.8	17.0	71.1
Anthracene		4.77	8.37	6.81	4.91	3.73	5.72	1.71	1.31	12.2
C1 Phen.+Anthra.		27.6	54.7	47.3	62.7	52.6	62.1	21.2	21.2	178
C2 Phen.+Anthra.		50.5	80.5	73.5	116	83.0	109	37.0	38.5	397
C3 Phen.+Anthra.		45.0	50.8	53.1	78.2	56.7	64.5	30.9	29.9	343
C4 Phen.+Anthra.		16.6	20.8	17.9	25.1	15.5	21.0	11.1	10.1	113
Fluoranthene		124	265	286	146	160	133	102	93.8	277
Pyrene		103	218	199	105	115	96.7	79.7	72.1	219
Benz[a]anthracene		19.5	62.5	44.8	25.9	33.1	22.6	14.0	20.6	56.9
Chrysene		32.8	65.5	72.9	39.7	43.8	36.4	28.0	24.4	79.8
Sum Benzofluoranthenes		38.3	48.9	59.8	30.4	33.2	33.5	26.6	26.4	70.0
Benzo[e]pyrene		31.9	39.1	47.4	22.8	26.7	22.8	19.6	21.1	53.6
Benzo[a]pyrene		12.9	6.82	13.9	6.28	5.87	7.32	5.11	4.77	11.7
Perylene		7.67	3.59	13.3	3.70	5.16	3.52	3.87	7.09	6.85
Indeno[1,2,3-cd]pyrene		8.27	8.23	12.7	4.75	6.60	7.34	6.76	7.08	9.78
Benzo[ghi]perylene		16.3	15.5	22.0	10.1	13.3	10.5	11.0	10.9	28.1
Sum MW 276 PAHs		33.0	29.6	44.0	31.9	29.1	30.4	26.7	25.7	59.6
Dibenz[a,h]anthracene		2.36	10.3	4.66	0.000	6.97	0.000	1.97	1.56	4.10
Sum MW 278 PAHs		12.5	0.007	15.3	0.000	44.1	0.000	7.99	7.31	21.4
Coronene		2.86	1.78	2.53	1.36	1.04	0.805	2.11	1.31	3.72
Sum MW 302 PAHs		2.63	7.07	14.9	2.95	7.13	4.49	10.2	7.87	9.14
10-Benzotriazole		156	193	62.7	422	559	363	199	177	233
Chloro-Benzotriazole		21.0	29.2	13.1	33.6	73.5	26.1	28.5	26.9	22.0

TABLE I-5.   POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB DRY WT) IN MYTILUS EDULIS

Compound	Sampnum Station Date	798146 AH5 890606	798148 AH5 890606	798150 MV1 890606	798152 MV1 890606	798154 TTN2 890606	798156 TTN2 890606	798158 LAB 890606	798161 LAB 890606
Fluorene		10.6	9.07	0.116	3.78	4.13	18.1	15.6	4.21
Phenanthrene		25.0	22.9	0.494	12.1	12.2	13.2	22.6	15.5
Anthracene		8.89	6.95	0.065	3.95	4.25	3.96	2.82	2.16
C1 Phen.+Anthra.		42.7	37.5	0.381	17.4	17.7	16.7	14.9	15.1
C2 Phen.+Anthra.		74.9	64.3	0.585	29.4	28.5	28.7	16.5	20.3
C3 Phen.+Anthra.		56.9	49.6	0.554	34.7	28.3	33.8	16.0	18.3
C4 Phen.+Anthra.		24.0	20.6	0.334	19.8	14.0	12.4	7.58	8.71
Fluoranthene		322	513	2.24	81.9	146	176	62.3	54.0
Pyrene		367	321	1.99	82.2	118	140	37.8	35.1
Benz[a]anthracene		29.3	33.5	0.432	18.2	20.5	16.0	7.03	7.77
Chrysene		65.3	58.9	0.532	21.6	29.9	27.4	14.5	11.8
Sum Benzofluoranthenes		41.6	46.4	0.874	50.0	42.5	37.4	20.2	21.6
Benzo[e]pyrene		44.1	41.5	0.795	40.6	41.4	34.0	17.2	17.7
Benzo[a]pyrene		3.45	4.01	0.176	9.57	6.94	6.91	3.93	4.39
Perylene		3.91	5.23	0.102	4.77	3.35	3.94	2.73	1.92
Indeno[1,2,3-cd]pyrene		5.78	6.25	0.240	14.3	11.7	8.57	5.91	5.12
Benzo[ghi]perylene		10.9	10.3	0.361	21.0	18.8	14.9	10.6	9.72
Sum MW 276 PAHs		23.8	24.6	0.814	45.1	38.9	36.9	23.2	19.8
Dibenz[a,h]anthracene		1.74	1.72	0.087	4.75	3.60	2.96	1.84	1.71
Sum MW 278 PAHs		8.35	9.99	0.304	17.1	13.6	11.9	9.65	7.55
Coronene		2.28	2.60	0.081	5.02	4.48	2.67	3.12	2.03
Sum MW 302 PAHs		9.26	9.38	0.324	20.3	16.2	13.5	12.7	7.97
10-Benzotriazole		314	306	8.79	659	664	551	345	342
Chloro-Benzotriazole		48.3	41.5	1.78	93.3	90.8	93.8	47.4	51.5

TABLE I-6.   POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB DRY WT) IN CRASSOSTREA VIRGINICA

Compound	Sampnum | Station | Date |	798094 AHLN 881212	798095 AHLW 881212	798096 AHLM 881212	798097 PI 881212	798098 PI 881212	798099 PI 881212
Fluorene		11.2	10.9	11.0	5.93	5.92	5.10
Phenanthrene		37.2	35.7	34.5	15.3	24.5	16.1
Anthracene		6.31	7.39	5.90	2.18	2.50	1.57
C1 Phen.+Anthra.		61.9	46.9	38.8	15.5	20.0	13.6
C2 Phen.+Anthra.		132.	82.6	85.3	38.9	41.5	28.7
C3 Phen.+Anthra.		68.7	39.4	50.8	27.3	31.3	19.1
C4 Phen.+Anthra.		19.4	12.1	14.7	12.6	12.6	8.96
Fluoranthene		435.	370.	336.	129.	129.	85.0
Pyrene		216.	180.	158.	62.5	67.0	46.5
Benz[a]anthracene		45.4	32.9	60.1	13.1	25.6	13.3
Chrysene		89.0	82.0	70.5	50.4	35.8	24.3
Sum Benzofluorathenes		21.2	17.3	25.0	25.5	28.3	13.2
Benzo[e]pyrene		16.8	11.6	14.3	14.3	12.4	8.05
Benzo[a]pyrene		1.14	1.66	1.28	1.51	1.73	0.667
Perylene		1.81	0.992	1.56	0.405	0.626	0.511
Indeno[1,2,3-cd]pyrene		0.599	0.362	0.235	0.969	1.71	0.242
Benzo[ghi]perylene		1.65	1.09	0.751	2.68	3.30	1.19
Sum MW 276 PAHs		4.55	4.60	2.72	8.87	7.51	1.94
Dibenz[a,h]anthracene		0.197	0.346	0.237	1.15	0.954	0.179
Sum MW 278 PAHs		1.84	2.37	2.07	9.56	3.85	0.611
Coronene		0.521	0.393	0.204	0.329	1.99	0.187
Sum MW 302 PAHs		2.59	2.69	1.99	4.66	2.49	0.455
10-Benzotriazole		14.9	13.7	5.91	1.83	24.8	42.2
Chloro-Benzotriazole		5.36	5.29	4.66	1.58	6.28	7.65

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TABLE I-7. DISSOLVED POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (UG/L) IN WATER SAMPLES

| Compound | Sampnum | 798209 | 798210 | 798211 | 798212 |
| | Station | AH2 | AH2 | MV1 | MV1 |
	Date	890802	890802	890802	890802
Fluorene		0.00161	0.00129	0.00070	0.00094
Phenanthrene		0.00239	0.00153	0.00234	0.00136
Anthracene		0.00022	0.00034	0.00025	0.00020
C1 Phen.+Anthra.		0.00131	0.00116	0.00281	0.00101
C2 Phen.+Anthra.		0.00112	0.00093	0.00299	0.00086
C3 Phen.+Anthra.		0.00056	0.00058	0.00223	0.00041
C4 Phen.+Anthra.		0.00018	0.00000	0.00087	0.00000
Fluoranthene		0.00181	0.00130	0.00260	0.00162
Pyrene		0.00112	0.00105	0.00254	0.00166
Benz[a]anthracene		0.00007	0.00005	0.00020	0.00011
Chrysene		0.00052	0.00036	0.00104	0.00048
Sum Benzofluoranthenes		0.00031	0.00041	0.00078	0.00039
Benzo[e]pyrene		0.00011	0.00012	0.00025	0.00023
Benzo[a]pyrene		0.00004	0.00000	0.00005	0.00008
Perylene		0.00001	0.00002	0.00001	0.00005
Indeno[1,2,3-cd]pyrene		0.00006	0.00000	0.00012	0.00004
Benzo[ghi]perylene		0.00006	0.00002	0.00017	0.00008
Sum MW 276 PAHs		0.00013	0.00002	0.00034	0.00016
Dibenz[a,h]anthracene		0.00002	0.00001	0.00001	0.00000
Sum MW 278 PAHs		0.00003	0.00001	0.00012	0.00008
Coronene		0.00002	0.00000	0.00012	0.00000
Sum MW 302 PAHs		0.00000	0.00000	0.00007	0.00000
10-Benzotriazole		0.00007	0.00007	0.00028	0.00014
Chloro-Benzotriazole		0.00002	0.00226	0.00010	0.00010

TABLE I-8. PARTICULATE POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB) IN WATER SAMPLES

Compound	Sampnum Station Date	798209 AH2 890802	798210 AH2 890802	798211 MV1 890802	798212 MV1 890802
Fluorene		0.00009	0.00000	0.00014	0.00022
Phenanthrene		0.00064	0.00113	0.00117	0.00174
Anthracene		0.00011	0.00010	0.00015	0.00039
C1 Phen.+Anthra.		0.00044	0.00100	0.00113	0.00131
C2 Phen.+Anthra.		0.00000	0.00083	0.00120	0.00129
C3 Phen.+Anthra.		0.00000	0.00040	0.00064	0.00078
C4 Phen.+Anthra.		0.00011	0.00000	0.00018	0.00018
Fluoranthene		0.00109	0.00177	0.00184	0.00342
Pyrene		0.00104	0.00166	0.00163	0.00351
Benz[a]anthracene		0.00029	0.00053	0.00046	0.00118
Chrysene		0.00080	0.00152	0.00105	0.00228
Sum Benzofluorathenes		0.00151	0.00318	0.00202	0.00491
Benzo[e]pyrene		0.00062	0.00127	0.00073	0.00200
Benzo[a]pyrene		0.00056	0.00124	0.00075	0.00213
Perylene		0.00014	0.00041	0.00017	0.00055
Indeno[1,2,3-cd]pyrene		0.00052	0.00111	0.00075	0.00190
Benzo[ghi]perylene		0.00058	0.00122	0.00081	0.00194
Sum MW 276 PAHs		0.00161	0.00281	0.00194	0.00544
Dibenz[a,h]anthracene		0.00017	0.00050	0.00022	0.00066
Sum MW 278 PAHs		0.00063	0.00126	0.00116	0.00252
Coronene		0.00019	0.00048	0.00042	0.00088
Sum MW 302 PAHs		0.00000	0.00205	0.00194	0.00416
10-Benzotriazole		0.00015	0.00056	0.00118	0.00199
Chloro-Benzotriazole		0.00011	0.00033	0.00037	0.00076

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TABLE I-9. POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB) IN SEEP SAMPLES

Compound	Sampnum Station Date	798264 LANDS 890927	798265 LANDS 890927
Fluorene		0.0110	0.114
Phenanthrene		0.0863	1.51
Anthracene		0.0267	0.296
C1 Phen.+Anthra.		0.0443	0.532
C2 Phen.+Anthra.		0.0323	0.328
C3 Phen.+Anthra.		0.0196	0.185
C4 Phen.+Anthra.		0.0267	0.122
Fluoranthene		0.231	2.89
Pyrene		0.242	2.50
Benz[a]anthracene		0.134	1.10
Chrysene		0.151	1.27
Sum Benzofluorathenes		0.356	2.70
Benzo[e]pyrene		0.152	1.19
Benzo[a]pyrene		0.185	1.43
Perylene		0.0428	0.373
Indeno[1,2,3-cd]pyrene		0.186	1.63
Benzo[ghi]perylene		0.153	1.38
Sum MW 276 PAHs		0.461	4.37
Dibenz[a,h]anthracene		0.0657	0.492
Sum MW 278 PAHs		0.177	1.57
Coronene		0.0591	0.509
Sum MW 302 PAHs		0.3710	3.75
10-Benzotriazole		0.0301	0.0644
Chloro-Benzotriazole		0.0103	0.0477

TABLE I-10. POLYCYCLIC AROMATIC HYDROCARBON CONCENTRATIONS (PPB) IN GROUND WATER SAMPLES

Compound	Sampnum Station Date	798279 LND 891116	798280 LND 891116	798281 LND 891116	798282 LND 891116
Fluorene		0.00096	0.00358	0.00109	0.00868
Phenanthrene		0.00614	0.00677	0.00538	0.0882
Anthracene		0.00236	0.00240	0.00103	0.0151
C1 Phen.+Anthra.		0.00781	0.00544	0.00519	0.0443
C2 Phen.+Anthra.		0.00567	0.00568	0.00318	0.0313
C3 Phen.+Anthra.		0.00362	0.00336	0.00154	0.0160
C4 Phen.+Anthra.		0.00079	0.00108	0.00082	0.00771
Fluoranthene		0.0169	0.01910	0.01130	0.312
Pyrene		0.0155	0.01670	0.00957	0.269
Benz[a]anthracene		0.00836	0.00834	0.00588	0.211
Chrysene		0.0113	0.0101	0.00865	0.263
Sum Benzofluorathenes		0.0231	0.0222	0.02310	0.752
Benzo[e]pyrene		0.0111	0.0111	0.0119	0.336
Benzo[a]pyrene		0.0105	0.00990	0.00923	0.336
Perylene		0.00441	0.00368	0.00178	0.0863
Indeno[1,2,3-cd]pyrene		0.0137	0.0137	0.0142	0.486
Benzo[ghi]perylene		0.0137	0.0120	0.0133	0.411
Sum MW 276 PAHs		0.0382	0.0346	0.0368	1.20
Dibenz[a,h]anthracene		0.00501	0.00427	0.00429	0.168
Sum MW 278 PAHs		0.0155	0.0116	0.0131	0.462
Coronene		0.00893	0.00519	0.00277	0.13
Sum MW 302 PAHs		0.0220	0.0308	0.0155	0.999
10-Benzotriazole		0.00103	0.00034	0.00126	0.00076
Chloro-Benzotriazole		0.00	0.00010	0.00045	0.00

APPENDIX J

STEROL CONCENTRATIONS*

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* The following chemical concentration data are organized by sample matrix. Individual field replicates are identified by unique sample numbers (SAMPNUM). Instrumental replicates are identified by REP. Station designations follow the terminology described in the main body of this report. Sample collection dates follow the format YYMMDD. All contaminant abbreviations and acronyms are described in the text.

Entries of "0.0" or "nd" indicate contaminant levels below analytical detection limits, rather than actual zero concentrations. Entries of "nm" indicate the contaminant not to have been measured in that sample.

TABLE J-1.   STEROL CONCENTRATIONS (NG/G DRY WT) IN SUBTIDAL
SEDIMENTS

Sampnum	Stat	Date	Coprostanol	Cholesterol	Cholestanol
798000	AH8	891031	1.29	5.39	2.61
798006	AH5	881103	1.02	4.46	2.05
798007	AH10	890209	2.31	7.27	3.30
798018	NJ1	881031	0.458	2.45	0.813
798019	NJ2	881031	0.398	2.44	0.712
798021	NJ4	881101	0.256	2.00	0.478
798022	NJ5	881101	0.281	2.49	0.583
798023	GB1	881031	0.297	2.34	0.494
798024	GB2	881031	nd	1.44	nd
798025	GB3	881031	nd	0.990	0.249
798026	GB4	881031	0.421	3.18	1.16
798027	GB5	881031	0.140	1.12	0.333
798030	MV3	881101	0.921	4.16	1.46
798031	MV4	881101	1.12	4.67	1.72
798032	MV5	881101	1.08	4.72	1.70
798033	PC1	890209	2.67	10.1	5.31
798034	PC2	890209	5.51	13.5	5.46
798035	PC3	890209	3.12	11.4	5.40
798036	PC4	890209	3.07	9.14	4.95
798037	PC5	890209	2.24	6.99	3.26

TABLE J-2.   STEROL CONCENTRATIONS (NG/G DRY WT) IN INTERTIDAL
SEDIMENTS

Sampnum	Stat	Date	Coprostanol	Cholesterol	Cholestanol
798038	AH12	881221	0.416	2.20	0.721
798040	AH14	881223	0.301	1.54	0.532
798041	MP1	890103	nd	0.148	nd
798044	CC1	881222	nd	nd	nd

TABLE J-3. STEROL CONCENTRATIONS (NG/G DRY WT) IN SUBTIDAL
            SEDIMENTS OBTAINED BY GRAVITY CORE

Sampnum	Stat[1]	Date	Horizon (cm)	Coprostanol	Cholesterol	Cholestanol
798213	AHC	890213	0-2	1.95	8.11	2.48
798214	AHC	890213	18-20	nd	nd	nd
798215	AHC	890213	26-28	nd	nd	nd

[1] Composit sample from 5 separate gravity cores
    collected at stations AH2, AH3, AH5, AH8, and AH10.

APPENDIX K

BUTYLTIN CONCENTRATIONS*

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* The following chemical concentration data are organized by sample matrix. Individual field replicates are identified by unique sample numbers (SAMPNUM). Instrumental replicates are identified by REP. Station designations follow the terminology described in the main body of this report. Sample collection dates follow the format YYMMDD. All contaminant abbreviations and acronyms are described in the text.

Entries of "0.0" or "nd" indicate contaminant levels below analytical detection limits, rather than actual zero concentrations. Entries of "nm" indicate the contaminant not to have been measured in that sample.

TABLE K-1. BUTYLTIN CONCENTRATIONS (UG/G DRY WT) IN SUBTIDAL
SEDIMENTS

Sampnum	Stat	Rep	Date	Wet:dry ratio	Mono-butyltin	Di-butyltin	Tri-butyltin
798000	AH8	1	881031	0.86	0.108	0.100	0.106
		2			0.076	0.097	0.094
		3			0.077	0.099	0.107
798001	AH3	1	881031	0.92	0.02	0.06	0.05
		2			0.03	0.06	0.05
		3			0.02	0.06	0.05
798002	AH2	1	881103	0.91	0.02	0.04	0.04
		2			0.02	0.04	0.04
		3			0.02	0.04	0.04
798006	AH5	1	881103	0.90	0.074	0.054	0.088
		2			0.084	0.068	0.126
		3			0.079	0.059	0.096
798028	MV1	1	881101	0.93	0.01	0.02	0.02
		2			nd	0.01	0.01
		3			nd	0.02	0.01
798029	MV2	1	881101	0.82	0.12	0.10	0.06
		2			nd	0.02	0.02
		3			0.01	0.02	0.02

TABLE K-2. BUTYLTIN CONCENTRATIONS (UG/G DRY WT) IN INTERTIDAL
SEDIMENTS

Sampnum	Stat	Rep	Date	Wet:dry ratio	Mono-butyltin	Di-butyltin	Tri-butyltin
798039	AH13	1	881223	1.00	0.063	0.030	0.046
		2			0.061	0.029	0.040
		3			0.062	0.030	0.041
798042	MP2	1	890103	1.00	0.037	0.015	0.038
		2			0.038	0.015	0.031
		3			0.038	0.015	0.038
798043	MP3	1	890103	0.98	0.038	0.015	0.031
		2			0.038	0.015	0.031
		3			0.038	0.015	0.032
798145	FDA	1	890419	0.98	0.038	0.015	0.040
		2			0.038	0.015	0.043
		3			0.050	0.022	0.050

TABLE K-3.   BUTYLTIN CONCENTRATIONS (UG/G DRY WT) IN MERCENARIA
             MERCENARIA

Sampnum	Stat	Rep	Date	Wet:dry ratio	Mono-butyltin	Di-butyltin	Tri-butyltin
798056	AH8	1	881109	0.11	0.243	0.221	1.191
		2			0.242	0.220	1.225
		3			0.245	0.225	1.136
798057	AH3	1	881109	0.16	nd	0.12	1.15
798058	AH2	1	881109	0.13	nd	0.12	0.82
798062	AH5	1	881109	0.11	0.245	0.272	0.928
		2			0.241	0.262	0.895
		3			0.245	0.263	0.879
789084	MV1	1	881109	0.13	nd	0.08	0.36
798085	MV2	1	881109	0.12	nd	nd	0.44

TABLE K-4.   BUTYLTIN CONCENTRATIONS (UG/G DRY WT) IN MYA
             ARENARIA

Sampnum	Stat	Rep	Date	Wet:dry ratio	Mono-butyltin	Di-butyltin	Tri-butyltin
798047	AH12	1	881221	0.08	0.377	0.404	8.892
		2			0.388	0.372	8.564
		3			0.380	0.410	8.969
798050	MP1	1	890103	0.16	0.185	0.085	1.208
		2			0.188	0.086	1.176
		3			0.189	0.087	1.240
798052	MP3	1	890103	0.20	0.150	0.086	1.451
		2			0.154	0.100	1.361
		3			0.148	0.068	1.386
798100	FDA	1	890104	0.11	0.273	0.270	5.456
		2			0.277	0.277	5.100
		3			0.270	0.259	5.176

TABLE K-5. BUTYLTIN CONCENTRATIONS (UG/G DRY WT) IN MYTILUS
EDULIS

Sampnum	Stat	Rep	Date	Wet:dry ratio	Mono-butyltin	Di-butyltin	Tri-butyltin
798146	AH5	1	890606	0.19	0.185	0.372	0.384
		2			0.189	0.356	0.384
798148	AH5	1	890606	0.19	0.176	0.808	0.379
		2			0.185	0.809	0.386
798150	MV1	1	890606	0.16	0.219	1.007	0.295
		2			0.206	1.018	0.299
798152	MV1	1	890606	0.15	0.247	0.910	0.350
		2			0.217	0.868	0.318
798154	TTN2	1	890606	0.16	0.165	0.773	0.360
		2			0.168	0.757	0.352
798156	TTN2	1	890606	0.17	0.157	0.948	0.353
		2			0.160	0.938	0.337
798158	LAB	1	890606	0.16	0.168	0.890	0.340
		2			0.165	0.910	0.338
798160	LAB	1	890606	0.15	0.175	0.704	0.350
		2			0.178	0.671	0.355

APPENDIX L

VOLATILE ORGANIC COMPOUND CONCENTRATIONS*

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* The following chemical concentration data are organized by sample matrix. Individual field replicates are identified by unique sample numbers (SAMPNUM). Instrumental replicates are identified by REP. Station designations follow the terminology described in the main body of this report. Sample collection dates follow the format YYMMDD. All contaminant abbreviations and acronyms are described in the text.

Entries of "0.0" or "nd" indicate contaminant levels below analytical detection limits, rather than actual zero concentrations. Entries of "nm" indicate the contaminant not to have been measured in that sample.

TABLE L-1. CONCENTRATIONS OF VOLATILE ORGANIC COMPOUNDS (UG/L) IN WHOLE WATER SAMPLES

Compound	Sampnum Station Date	798209 AH2 890802	798210 AH2 890802	798211 MV1 890802	798212 MV1 890802
Vinyl chloride		nd	nd	nd	nd
1,1-Dichloroethene		nd	nd	nd	nd
Methylene chloride		<1	<1	<1	<1
Trans-1,2-dichloroethene		nd	nd	nd	nd
1,1-dichloroethane		nd	nd	nd	nd
Chloroform		nd	nd	nd	nd
1,1,1-Trichloroethane		nd	nd	nd	nd
Carbon tetrachloride		nd	nd	nd	nd
1,2-dichloroethane		nd	nd	nd	nd
Trichloroethene		nd	nd	nd	nd
1,2-Dichloropropane		nd	nd	nd	nd
Bromodichloromethane		nd	nd	nd	nd
2-Chloroethylvinyl ether		nd	nd	nd	nd
Cis-1,3-dichloropropene		nd	nd	nd	nd
Trans-1,3-dichloropropene		nd	nd	nd	nd
1,1,2-Trichloroethane		nd	nd	nd	nd
Tetrachloroethene		nd	nd	nd	nd
Dibromochloromethane		nd	nd	nd	nd
Chlorobenzene		nd	nd	nd	nd
Bromoform		nd	nd	nd	nd
1,1,2,2-Tetrachlorobenzene		nd	nd	nd	nd
1,3-Dichlorobenzene		nd	nd	nd	nd
1,4-Dichlorobenzene		nd	nd	nd	nd
1,2-Dichlorobenzene		nd	nd	nd	nd
Cis-1,2-dichloroethene		0.1	nd	nd	nd
Acetone		+	+	+	+
Methyl-t-butyl ether		nd	nd	nd	nd
Benzene		nd	nd	nd	nd
Toluene		nd	nd	0.1	<0.1
Ethylbenzene		nd	nd	nd	nd
m,p-Xylene		nd	nd	nd	nd
o-Xylene		nd	nd	nd	nd

L-3

TABLE L-2.   CONCENTRATIONS OF VOLATILE ORGANIC COMPOUNDS (UG/L) IN LANDFILL SEEP SAMPLES

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Compound	Sampnum Station Date	798196 LNDN 890802	798197 LNDN 890802	798198 LNDN 890802	798199 LNDW 890802	798200 LNDW 890802	798201 LNDW 890802	798202 LNDS 890802	798203 LNDS 890802	798204 LNDS 890802	798205 LNDS 890802
Vinyl chloride		nd	nd	nd	nd	nd	nd	+	+	nd	nd
1,1-Dichloroethene		nd	nd	nd	nd	nd	nd	0.1	nd	nd	nd
Methylene chloride		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Trans-1,2-dichloroethene		0.5	nd	nd	nd	nd	nd	8.0	nd	24.3	0.3
1,1-dichloroethane		0.2	nd	nd	nd	nd	nd	nd	nd	nd	nd
Chloroform		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1,1,1-Trichloroethane		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Carbon tetrachloride		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1,2-dichloroethane		1.0	nd	nd	nd	nd	nd	61.6	101.2	0.4	nd
Trichloroethene		nd	nd	0.3	nd	nd	0.3	3.3	nd	0.3	nd
1,2-Dichloropropane		0.1	nd	nd	nd	nd	nd	nd	nd	nd	nd
Bromodichloromethane		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2-Chloroethylvinyl ether		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Cis-1,3-dichloropropene		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Trans-1,3-dichloropropene		0.3	nd	nd	nd	nd	nd	nd	0.8	nd	nd
1,1,2-Trichloroethane		nd	nd	nd	nd	nd	nd	2.3	2.9	nd	nd
Tetrachloroethene		nd	nd	1.6	nd	0.1	<0.1	nd	nd	nd	nd
Dibromochloromethane		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Chlorobenzene		0.1	nd	nd	nd	nd	nd	nd	nd	nd	nd
Bromoform		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1,1,2,2-Tetrachlorobenzene		nd	nd	nd	nd	nd	nd	3.8	5.8	nd	nd
1,3-Dichlorobenzene		nd	nd	nd	nd	nd	nd	0.7	0.4	nd	nd
1,4-Dichlorobenzene		nd	nd	nd	nd	nd	nd	nd	nd	nd	0.1
1,2-Dichlorobenzene		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
cis-1,2-dichloroethene		4.5	nd	0.3	nd	nd	nd	62.7	170.5	0.3	0.6
Acetone		+	+	+	+	nd	nd	nd	nd	nd	nd
Methyl-t-butyl ether		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzene		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Toluene		nd	nd	nd	0.1	nd	nd	nd	nd	nd	nd
Ethylbenzene		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
m,p-Xylene		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
o-Xylene		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

(continued)

TABLE L-2 (continued).   CONCENTRATIONS OF VOLATILE ORGANIC COMPOUNDS (UG/L) IN LANDFILL SEEP SAMPLES

Compound	Sampnum Station Date	798263 LANDE 890927	798264 LANDS 890927	798265 LANDS 890927	798266 LANDS 890927	798267 LANDS 890927
Vinyl chloride		nd	nd	nd	nd	nd
1,1-Dichloroethene		nd	0.1	nd	nd	0.1
Methylene chloride		0.3	0.3	0.1	0.3	0.9
Trans-1,2-dichloroethene		nd	5.2	0.2	1.1	nd
1,1-dichloroethane		nd	nd	0.1	0.4	nd
Cis-1,2-dichloroethene		nd	48.1	0.3	nd	nd
Chloroform		nd	nd	nd	nd	0.3
1,1,1-Trichloroethane		nd	nd	nd	nd	0.6
Carbon tetrachloride		nd	nd	nd	nd	nd
1,2-dichloroethane		nd	9.5	nd	nd	nd
Trichloroethene		nd	0.2	nd	nd	nd
1,2-Dichloropropane		nd	nd	nd	nd	nd
Bromodichloromethane		nd	nd	nd	nd	nd
2-Chloroethylvinyl ether		nd	nd	nd	nd	nd
Cis-1,3-dichloropropene		nd	nd	nd	nd	nd
Trans-1,3-dichloropropene		nd	nd	nd	nd	nd
1,1,2-Trichloroethane		nd	0.4	nd	nd	nd
Tetrachloroethene		0.1	0.1	nd	nd	nd
Dibromochloromethane		nd	nd	nd	nd	nd
Chlorobenzene		nd	nd	nd	nd	nd
Bromoform		nd	nd	nd	nd	nd
1,1,2,2-Tetrachlorobenzene		0.1	2.8	nd	nd	nd
1,3-Dichlorobenzene		nd	0.1	nd	nd	nd
1,4-Dichlorobenzene		nd	nd	nd	nd	nd
1,2-Dichlorobenzene		nd	nd	nd	nd	nd
Acetone		((----------- not measured -------------))				
Methyl-t-butyl ether		+	+	+	+	+
Benzene		nd	nd	nd	1.0	nd
Toluene		0.2	nd	nd	0.1	nd
Ethylbenzene		nd	nd	nd	3.5	nd
m,p-Xylene		nd	nd	nd	nd	nd
o-Xylene		nd	nd	nd	nd	nd

TABLE L-3. CONCENTRATIONS OF VOLATILE ORGANIC COMPOUNDS (UG/L) IN GROUND WATER SAMPLES

Compound	Sampnum Station Date	798252 LND (PIT) 890919	798279 LND (WELL) 891116	798280 LND (WELL) 891116	798281 LND (WELL) 891116	798282 LND (WELL) 891116
Vinyl chloride		nd	nd	nd	+	nd
1,1-Dichloroethene		nd	nd	nd	nd	nd
Methylene chloride		0.5	0.4	0.6	1.8	0.7
Trans-1,2-dichloroethene		nd	nd	0.5	nd	nd
1,1-dichloroethane		nd	nd	nd	nd	nd
Cis-1,2-dichloroethene		nd	nd	5.5	90.3	nd
Chloroform		nd	nd	0.2	nd	nd
1,1,1-Trichloroethane		nd	nd	0.2	nd	nd
Carbon tetrachloride		nd	nd	nd	nd	nd
1,2-dichloroethane		nd	nd	0.2	1.0	nd
Trichloroethene		0.1	nd	2.7	1.9	nd
1,2-Dichloropropane		nd	nd	nd	0.2	nd
Bromodichloromethane		nd	nd	nd	nd	nd
2-Chloroethylvinyl ether		nd	nd	nd	nd	nd
Cis-1,3-dichloropropene		nd	nd	nd	nd	nd
Trans-1,3-dichloropropene		nd	nd	nd	nd	nd
1,1,2-Trichloroethane		nd	nd	nd	0.2	nd
Tetrachloroethene		nd	nd	nd	nd	nd
Dibromochloromethane		nd	nd	nd	nd	nd
Chlorobenzene		1.9	0.1	20.5	nd	nd
Bromoform		nd	nd	nd	nd	nd
1,1,2,2-Tetrachlorobenzene		nd	nd	nd	nd	nd
1,3-Dichlorobenzene		0.3	nd	0.5	nd	nd
1,4-Dichlorobenzene		0.7	1.1	3.1	nd	nd
1,2-Dichlorobenzene		0.1	nd	nd	nd	nd
Acetone		(<---------- not measured ------------->)				
Methyl-t-butyl ether		nd	nd	nd	nd	nd
Benzene		13.	nd	3.6	nd	nd
Toluene		0.6	nd	2.0	nd	nd
Ethylbenzene		0.4	nd	+	nd	nd
m,p-Xylene		0.6	nd	+	nd	nd
o-Xylene		0.2	nd	+	nd	nd

APPENDIX M

SEDIMENT GRANULOMETRY*

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* The following geophysical data are organized by sample matrix. Individual field replicates are identified by unique sample numbers (SAMPNUM). Instrumental replicates are identified by REP. Station designations follow the terminology described in the main body of this report. Sample collection dates follow the format YYMMDD.

TABLE M-1. GRANULOMETRY OF SUBTIDAL SEDIMENTS

Sampnum	Stat	Rep	Date	Total weight (g)	Percent sand	Percent silt	Percent clay
798000	AH8	1	881031	5.46	3.66	37.55	58.79
798001	AH3	1	881031	5.17	4.06	54.55	41.39
798002	AH2	1	881103	6.15	5.85	38.54	55.61
798006	AH5	1	881103	6.65	4.66	44.36	50.98
798007	AH10	1	890209	6.49	18.80	53.78	27.42
		2		6.92	26.45	57.51	16.04
798018	NJ1	1	881031	7.61	26.81	49.28	23.91
798019	NJ2	1	881031	8.43	50.65	21.00	28.35
798020	NJ3	1	881101	6.02	52.82	30.73	16.45
798021	NJ4	1	881101	7.28	75.96	11.26	12.78
798022	NJ5	1	881101	10.53	75.31	13.58	11.11
798023	GB1	1	881031	7.31	93.30	2.60	4.10
798024	GB2	1	881031	10.24	95.31	2.34	2.35
798025	GB3	1	881031	7.18	94.29	2.92	2.79
798026	GB4	1	881031	6.79	82.03	6.19	11.78
798027	GB5	1	881031	7.95	92.08	2.26	5.66
798028	MV1	1	881101	4.91	31.77	34.22	34.01
798029	MV2	1	881101	6.35	18.27	29.76	51.97
798030	MV3	1	881101	7.12	34.83	27.95	37.22
798031	MV4	1	881101	5.92	9.12	60.05	30.83
		2		6.64	20.03	37.80	42.17
798032	MV5	1	881101	6.50	31.23	18.15	50.62
798033	PC1	1	880209	4.83	11.39	60.87	27.74
		2		4.94	18.62	34.01	47.37
798034	PC2	1	880209	4.69	19.83	29.64	50.53
798035	PC3	1	880209	4.84	12.60	30.17	57.23
798036	PC4	1	880209	6.17	38.74	22.69	38.57
798037	PC5	1	880209	4.89	7.16	27.61	65.23

TABLE M-2. GRANULOMETRY OF INTERTIDAL SEDIMENTS

Sampnum	Stat	Rep	Date	Total weight (g)	Percent sand	Percent silt	Percent clay
798038	AH12	1	881221	7.91	50.69	33.00	16.31
		2		10.43	58.01	31.26	10.73
798039	AH13	1	881223	7.66	92.69	4.05	3.26
798040	AH14	1	881223	8.64	83.10	8.33	8.57
798041	MP1	1	890103	8.13	96.31	1.35	2.34
798042	MP2	1	890103	10.19	90.08	5.00	4.92
798043	MP3	1	890103	8.16	76.96	13.85	9.19
798044	CC1	1	881222	8.99	92.88	2.67	4.45
798045	CC2	1	881222	7.88	88.83	6.37	4.44
798145	FDA	1	890419	6.76	65.38	23.37	11.25

TABLE M-3. GRANULOMETRY OF SUBTIDAL SEDIMENTS COLLECTED BY GRAVITY CORE

Sampnum	Stat	Rep	Date	Horizon (cm)	Total weight (g)	Percent sand	Percent silt	Percent clay
798213	AHC[1]	1	890213	0-2	6.25	16.64	59.84	23.52
798214	AHC	1	890213	18-20	5.81	12.22	63.51	24.27
798215	AHC	1	890213	26-28	5.80	5.86	50.69	43.45

[1] Composit sample from 5 separate gravity cores collected at stations AH2, AH3, AH5, AH8, and AH10.

TABLE M-4.   GRANULOMETRY OF LANDFILL SEDIMENTS

Sampnum	Stat	Rep	Date	Total weight (g)	Percent sand	Percent silt	Percent clay
798206	AHLN	1	890802	6.80	86.47	9.26	4.27

APPENDIX N

AMPHIPOD SEDIMENT BIOASSAY RESULTS

Test #1. Mean percent mortality of amphipods, _Ampelisca abdita_, exposed for 10 days in flowing filtered 20°C seawater to sediments from Allen Harbor and Greenwich Bay, Rhode Island. Control sediment was from central Long Island Sound. There were five replicates tested per treatment, with 30 amphipods per replicate. There were no significant differences between treatments ($p < .05$).

Station #	Station Location	%Mortality
control	Long Island Sound	2.7
798000	Allen Harbor	4.0
798001	Allen Harbor	6.0
798002	Allen Harbor	8.0
798006	Allen Harbor	8.7
798028	Mount View	10.7
798029	Mount View	2.0
798030	Mount View	4.7
798031	Mount View	2.0
798032	Mount View	3.3
798023	Greenwich Bay	10.0

Test #1. Percent mortality of amphipods, _Ampelisca abdita_, exposed for 10 days in flowing filtered 20°C seawater to sediments from Allen Harbor, Greenwich Bay, and Mount View, Rhode Island. Control sediment was from central Long Island Sound. Thirty amphipods were tested per replicate. There were no significant differences between treatments (p<.05).

Station #	Station Location	% Mortality	Mean
control	Long Island Sound	0	2.7
		3.3	
		0	
		10.0	
		0	
798000	Allen Harbor	6.7	4.0
		3.3	
		3.3	
		0	
		6.7	
798001	Allen Harbor	6.7	6.0
		3.3	
		6.7	
		13.3	
		0	
798002	Allen Harbor	3.3	8.0
		6.7	
		23.3	
		6.7	
		0	
798006	Allen Harbor	23.3	8.7
		10.0	
		0	
		6.7	
		3.3	
798028	Mount View	16.7	10.7
		0	
		13.3	
		20.0	
		3.3	
798029	Mount View	3.2	2.0
		3.3	
		0	
		0	
		3.3	

798030	Mount View	3.3 6.7 6.7 6.7 0	4.7
798031	Mount View	0 3.3 3.3 3.3 0	2.0
798032	Mount View	6.7 6.7 0 3.3 0	3.3
798023	Greenwich Bay	30.0 3.3 6.7 6.7 3.3	10.0

Test #2. Mean percent mortality of amphipods, _Ampelisca abdita_, exposed for 10 days in flowing filtered 20°C seawater to sediments from Allen Harbor and Greenwich Bay, Rhode Island. Control sediment was from central Long Island Sound. There were five replicates tested per treatment, with 30 amphipods per replicate. There were no significant differences between treatments ($p < .05$).

Station #	Station Location	%Mortality
control	Long Island Sound	6.6*
798003	Allen Harbor	6.0
798004	Allen Harbor	4.6
798005	Allen Harbor	2.7
798011	Allen Harbor mouth	2.0
798012	Allen Harbor mouth	0
798013	Allen Harbor mouth	6.0
798014	Allen Harbor mouth	4.7
798015	Allen Harbor mouth	4.0
798016	Allen Harbor mouth	0
798024	Greenwich Bay	4.0
798025	Greenwich Bay	2.7

* four replicates

Test #2. Percent mortality of amphipods, _Ampelisca abdita_, exposed for 10 days in flowing filtered 20 C seawater to sediments from Allen Harbor and Greenwich Bay, Rhode Island. Control sediment was from central Long Island Sound. Thirty amphipods were tested per replicate. There were no significant differences between treatments (p<.05).

Station #	Station Location	% Mortality	Mean
control	Long Island Sound	13.3	6.6 (11.3)*
		3.3	
		10.0	
		0	
		30.0	
798003	Allen Harbor	6.7	6.0
		10.0	
		0	
		6.7	
		6.7	
798004	Allen Harbor	10.0	4.6
		3.3	
		3.3	
		3.3	
		3.3	
798005	Allen Harbor	0	2.7
		0	
		10.0	
		0	
		3.3	
798011	Allen Harbor mouth	0	2.0
		0	
		6.7	
		0	
		3.3	
798012	Allen Harbor mouth	0	0
		0	
		0	
		0	
		0	
798013	Allen Harbor mouth	6.7	6.0
		0	
		10.0	
		6.7	
		6.7	

798014	Allen Harbor mouth	3.3	4.7
		10.0	
		0	
		0	
		10.0	
798015	Allen Harbor mouth	0	4.0
		0	
		10.0	
		3.3	
		6.7	
798016	Allen Harbor mouth	0	0
		0	
		0	
		0	
		0	
798024	Greenwich Bay	6.7	4.0
		6.7	
		6.7	
		0	
		0	
798025	Greenwich Bay	6.7	2.7
		0	
		3.3	
		3.3	
		0	

* Only 4 replicates were included in the data analysis; mean in parentheses is for 5 replicates. When the fifth replicate (30% mortality) was included, the control treatment was significantly different (p<.05) than 798012 and 798016, since there was no mortality in any of the exposure containers used to test those samples. This was the only significance detected.

Test #3. Mean percent mortality of amphipods, _Ampelisca abdita_, exposed for 10 days in flowing filtered 20°C seawater to sediments from East Allen Harbor and North Jamestown, Narragansett Bay, Rhode Island. Control sediment was from central Long Island Sound. There were five replicates tested per treatment, with 30 amphipods per replicate. There were no significant differences between treatments ($p < .05$).

Station #	Station Location	%Mortality
control	Long Island Sound	6.0
798018	North Jamestown	6.7
798019	North Jamestown	4.0
798020	North Jamestown	4.7
798021	North Jamestown	3.3
798022	North Jamestown	4.7
798039	East Allen Harbor	12.0
798041	East Allen Harbor	11.3
798042	East Allen Harbor	8.7
798043	East Allen Harbor	5.3
798044	East Allen Harbor	2.0
798045	East Allen Harbor	10.0

Test #3. Percent mortality of amphipods, _Ampelisca abdita_, exposed for 10 days in flowing filtered 20°C seawater to sediments from East Allen Harbor and North Jamestown, Narragansett Bay, Rhode Island. Control sediment was from central Long Island Sound. Thirty amphipods were tested per replicate. There were no significant differences between treatments ($p < .05$).

Station #	Station Location	% Mortality	Mean
control	Long Island Sound	3.3	6.0
		6.7	
		3.3	
		6.7	
		10.0	
798018	North Jamestown	3.3	6.7
		6.7	
		6.7	
		16.7	
		0	
798019	North Jamestown	10.0	4.0
		3.3	
		0	
		3.3	
		3.3	
798020	North Jamestown	6.7	4.7
		3.3	
		6.7	
		6.7	
		0	
798021	North Jamestown	3.3	3.3
		6.7	
		0	
		3.3	
		3.3	
798022	North Jamestown	6.7	4.7
		3.3	
		3.3	
		0	
		10.0	
798039	East Allen Harbor	6.7	12.0
		3.3	
		16.7	
		13.3	
		20.0	

798041	East Allen Harbor	20.0	11.3
		6.7	
		3.3	
		13.3	
		13.3	
798042	East Allen Harbor	0	8.7
		6.7	
		6.7	
		20.0	
		10.0	
798043	East Allen Harbor	6.7	5.3
		0	
		13.3	
		3.3	
		3.3	
798044	East Allen Harbor	0	2.0
		3.3	
		3.3	
		3.3	
		0	
798045	East Allen Harbor	6.7	10.0
		6.7	
		10.0	
		20.0	
		6.7	

Test #4. Mean percent mortality of amphipods, _Ampelisca abdita_, exposed for 10 days in flowing filtered 20°C seawater to sediments from Allen Harbor, Potter's Cove, and Greenwich Bay, Rhode Island. Control sediment was from central Long Island Sound. There were five replicates tested per treatment, with 30 amphipods per replicate. There were no significant differences between treatments ($p < .05$).

Station #	Station Location	%Mortality
control	Long Island Sound	1.3
798007	Allen Harbor	1.3
798026	Greenwich Bay	4.7
798027	Allen Harbor	6.0
798033	Potter's Cove	4.7
798034	Potter's Cove	2.0
798035	Potter's Cove	2.7
798036	Potter's Cove	6.7
798037	Potter's Cove	0
798038	Allen Harbor	4.7
798040	Allen Harbor	4.0

Test #4. Percent mortality of amphipods, _Ampelisca abdita_, exposed for 10 days in flowing filtered 20 C seawater to sediments from Allen Harbor, Greenwich Bay, and Potter's Cove, in Narragansett Bay, Rhode Island. Control sediment was from central Long Island Sound. Thirty amphipods were tested per replicate. There were no significant differences between treatments (p<.05).

Station #	Station Location	% Mortality	Mean
control	Long Island Sound	3.3	1.3
		0	
		0	
		0	
		3.3	
798026	Greenwich Bay	0	4.7
		3.3	
		0	
		13.3	
		6.7	
798027	Allen Harbor	3.3	6.0
		13.3	
		0	
		6.7	
		6.7	
798007	Allen Harbor	3.3	1.3
		0	
		0	
		0	
		3.3	
798038	Allen Harbor	10.0	4.7
		0	
		0	
		10.0	
		3.3	
798040	Allen Harbor	3.3	4.0
		0	
		3.3	
		10.0	
		3.3	
798033	Potter's Cove	6.7	4.7
		10.0	
		3.3	
		3.3	
		0	

798034	Potter's Cove	0	2.0
		0	
		6.7	
		0	
		3.3	
798035	Potter's Cove	0	2.7
		3.3	
		6.7	
		3.3	
		0	
798036	Potter's Cove	6.7	6.7
		13.3	
		3.3	
		3.3	
		6.7	
798037	Potter's Cove	0	0
		0	
		0	
		0	
		0	

Test #5. Mean percent mortality of amphipods, _Ampelisca abdita_, exposed for 10 days in flowing filtered 20°C seawater to sediment from Allen Harbor, Narragansett Bay, Rhode Island. Control sediment was from central Long Island Sound. There were five replicates tested per treatment, with 30 amphipods per replicate. A t-test indicated there was no significant difference between the test sediment and the control ($p < .05$).

Station #	Station Location	%Mortality
control	Long Island Sound	10.0
798145	Allen Harbor	8.6

Test #5. Percent mortality of amphipods, _Ampelisca abdita_, exposed for 10 days in flowing filtered 20°C seawater to sediment from Allen Harbor, Narragansett Bay, Rhode Island. Control sediment was from central Long Island Sound. There were five replicates tested per treatment, with 30 amphipods per replicate. A t-test indicated there was no significant difference between the test sediment and the control (p<.05).

Station #	Station Location	%Mortality	Mean
control	Long Island Sound	20.0	10.0
		10.0	
		3.3	
		10.0	
		6.7	
798145	Allen Harbor	6.7	8.6
		3.2	
		13.3	
		12.9	
		6.7	

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13. ABSTRACT (Maximum 200 words)

The Naval Construction Battalion Center (NCBC) in Davisville, Rhode Island, has been the subject of a joint ecological research program by the Navy and Environmental Protection Agency. Allen Harbor, a small embayment of Narragansett Bay adjacent to NCBC, was used to develop research and monitoring methods for ecological risk assessment. Two sites on the National Priorities List were of particular concern: (1) a 15-acre landfill used from 1946 to 1972 for the disposal of such wastes as solvents, PCB-contaminated oils, preservatives, sewage sludge, chromic acid, and construction rubble; and (2) a cement-lined pit that from 1960 to 1974 was the depository of calcium hypochlorite, chloride, and decontaminating solution.

Phase I of the study characterizes the ecology, natural resources, sediment, and water quality. A preliminary ecological risk assessment is developed. Exposure to and the effects of contamination are measured at both subtidal and intertidal stations. A T-shaped transect of stations projecting from the mouth of the harbor into Narragansett Bay proper is established to determine if measurable levels of contaminants and effects are reaching the Bay. A series of mid-Narragansett Bay stations provide a reference for comparing effects within Allen Harbor.

14. SUBJECT TERMS

Ampelisca abdita
Arbacia punctulata
atomic absorption spectroscopy
Clostridium perfringens
Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
condition indices
Crassostrea virginica
ecological risk assessment
gas chromatography
hematopoietic neoplasia
inductively coupled plasma emission spectroscopy
mass spectroscopy
Mercenaria mercenaria
metabolic cooperation
Mya arenaria

mycoplasm
Mytilus edulis
Narragansett Bay
Nephtys incisa
phagocytic index
polychlorinated biphenyl (PCB)
polycyclic aromatic hydrocarbon (PAH)
risk quotient
scope for growth
sediment toxicity
shell length
sister chromatid exchange
Superfund Amendments and Reauthorization Act (SARA)
tributyltin
volatile organic compound (VOC)

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